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FROM

The Commission

Courtesy of Manitoba Hydrographic Survey

NORMAN DAM IN WESTERN OUTLET OF LAKE OF THE WOODS. MAY 24, 1913

PLATE A

REPORT

TO

International Joint Commission

RELATING TO

OFFICIAL REFERENCE

RE

Lake of the Woods Levels

TEXT

BY

ADOLPH F. MEYER ARTHUR V. WHITE

Consulting Engineers

WASHINGTON, D. C., AND OTTAWA, CANADA

1916

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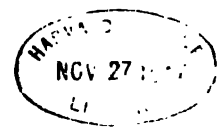

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NOTE

Only a small edition was issued of the Atlas referred to in this Report. The edition was chiefly for official use. Copies for purposes of reference, however, were filed in several of the Federal, State, Provincial, and large public libraries in both countries.

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LETTER OF TRANSMITTAL

SEPTEMBER 1ST, 1915.

INTERNATIONAL JOINT COMMISSION,
Washington, D. C., and Ottawa, Canada.

GENTLEMEN:

In accordance with instructions contained in your Resolution of October 1st, 1912, we beg to submit the following Report, containing data and considerations basic to the formulation of a reply to the questions contained in the following Official Reference, submitted to your honorable body by the Governments of the United States and of the Dominion of Canada, on June 27th, 1912.

DEPARTMENT OF STATE,
Washington, June 27, 1912.

INTERNATIONAL JOINT COMMISSION
OF THE UNITED STATES AND CANADA,
Washington, D. C.

SIRS:

I have the honor to inform you that at the joint request of the Government of the United States and of the Government of the Dominion of Canada, under the provisions of Article IX of the Treaty of January 11, 1909, between the United States and Great Britain, the questions or matters of difference set forth below, which have arisen between them involving the rights, obligations, or interests of each in relation to the other, or to the inhabitants of the other, along their common frontier between the United States and the Dominion of Canada, are hereby referred to the International Joint Commission for examination and report upon the facts and circumstances of the particular questions and matters referred, together with such conclusions and recommendations as may be appropriate.

The questions so referred are as follows:

1. In order to secure the most advantageous use of the waters of the Lake of the Woods and of the waters flowing into and from that Lake on each side of the boundary for domestic and sanitary purposes, for navigation and transportation purposes, and for fishing purposes, and for power and irrigation purposes, and also in order to secure the most advantageous use of the shores and harbours of the Lake and of the waters flowing into and from the Lake, is it practicable and desirable to maintain the surface of the Lake during the different seasons of the year at a certain stated level, and if so at what level?

2. If a certain stated level is recommended in answer to Question 1, and if such level is higher than the normal or natural level of the Lake, to what extent, if at all, would the Lake, when maintained at such level, overflow the low lands upon its southern border, or elsewhere on its border, and what is the value of the lands which would be submerged?

3. In what way or manner, including the construction and operation of dams or other works at the outlets and inlets of the Lake, or in the waters which are directly

or indirectly tributary to the Lake or otherwise is it possible and advisable to regulate the volume, use and outflow of the waters of the Lake so as to maintain the level recommended in answer to Question 1, and by what means or arrangement can the proper construction and operation of regulating works, or a system or method of regulation, be best secured and maintained in order to insure the adequate protection and development of all the interests involved on both sides of the boundary, with the least possible damage to all rights and interests, both public and private, which may be affected by maintaining the proposed level?

I have the honor to add that the Government of the United States will be glad to assist the Commission in obtaining any information which it may desire in the course of its investigation of the matters herein referred for its examination and report.

I am, Sirs,

Your obedient servant,

(Sgd) P. C. KNOX.

A letter corresponding to the above, under date of June 27th, 1912, was communicated by the British Embassy at Washington, D. C. It is reproduced as Appendix III, page 266 of this Report.

Recognizing the urgency of an early Report, we are presenting herewith, in three volumes, for your consideration, a large body of physical data and numerous studies, indicating the bearing of these data on a reply to the questions of the Official Reference. We feel constrained to state, however, that some of these data have been in hand only a short time, and may require further study and analysis. Moreover, we desire, later, to supplement this Report with such further data, and to direct your attention to such additional engineering considerations as the representations of interested parties expressed at subsequent Public Hearings, may merit.

ADOLPH F. MEYER,
ARTHUR V. WHITE,
Consulting Engineers.

SEPTEMBER 1ST, 1916.

Since the Public Hearings above referred to, additional physical data have been assembled and further studies completed. Tabular material has been added in the volume of Tables and additional graphs in the volume of Plates, and minor alterations have been made in this volume of Text. Further discussion of matters pertaining to phases of the investigation covered at the Public Hearings appears on pages 233 to 255 of this volume.

ADOLPH F. MEYER,
ARTHUR V. WHITE,
Consulting Engineers.

INTRODUCTION

A number of questions, centering about the level of the Lake of the Woods and the use of its waters, have been the subject of governmental investigation and international communication at various times in the past.

The Lake of the Woods is an irregularly shaped body of water 1485 square miles in area. The southerly portion, formerly known as the "Lake of the Woods," and bordered by low shores, is an expanse of relatively shallow, open water about 25 miles across, and is now known as the "Big Traverse." The northerly portion, known as the "Little Traverse," consists of numerous bays and inlets, bordered by bold rocky shores, and dotted with thousands of rocky islands.

The Lake of the Woods derives its water supply from a drainage area of 26,750 square miles, almost equally divided between the United States and Canada. Perhaps the most prominent characteristic of this drainage area is its abundance of rock-bound lakes. The aggregate area of all the lakes shown on the best available maps of the watershed of the Lake of the Woods constitutes 14.8 per cent of the total drainage area tributary to the Lake. About 70 per cent of this water area is in Canada and 30 per cent in the United States. The shores of almost all of the lakes, except the southerly shore of the Lake of the Woods and a portion of the shore of Rainy Lake, are bold and rocky, with here and there a fine sandy beach on a bay or inlet. These lakes already possess quite a reputation as summer resorts, and are visited annually by thousands of tourists. The region abounds in fish, and also in moose, deer, and other wild life.

Of the land area about 8,500 square miles, or 37 per cent of the total, consists of arable or semi-arable land, most of it, however, requiring drainage. A very small proportion of the total area, consisting mainly of narrow strips along the lakes and rivers, is under cultivation.

The general character of the soil and forest cover on the watershed is shown on the accompanying maps. One is at once impressed with the very large area of outcropping rock, covered with little or no soil except in the swamps and marshes.

In numerous places on the watershed, the ruins of mining structures indicate efforts to extract metals from the rocks. Very little successful mining is carried on, at present, on the watershed, although many persons have expressed the view that advances made in the art

of ore refining, etc., may now favor the successful working of the lower grade ores. A few mines are again being opened up.

About 63 per cent of the total land area is suitable, mainly, for forestry and possibly mining. This fact is being recognized and efforts are being made in both countries to have the non-agricultural land set aside as forest reserves. The reservations which have been made to date are shown on Plate 15 of the volume of Plates.

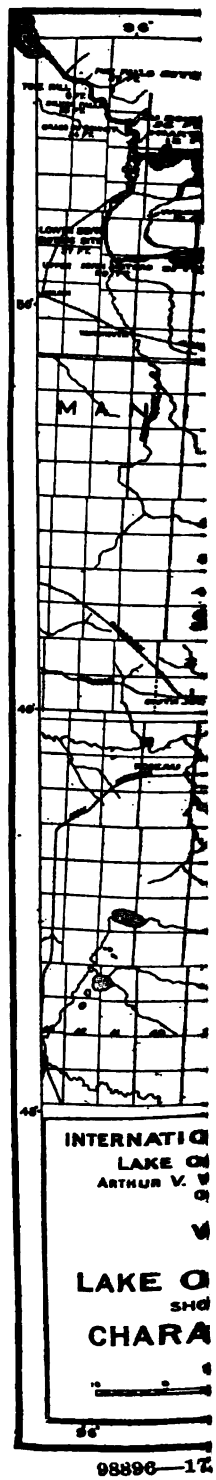
The principal drainage course of the watershed tributary to the Lake of the Woods is along the boundary between the two countries, and the general direction of the flow is northwesterly. A profile along the boundary waters is shown on the accompanying Plate. The south-eastern extremity of the drainage basin extends to within 15 miles of Lake Superior, where the divide has an elevation of approximately 1800 feet above sea-level datum. The outlets of the Lake of the Woods are in Canada, near Kenora and Keewatin, Ontario, at the extreme northern end of the Lake. After leaving the Lake the waters drain down the Winnipeg River into Lake Winnipeg, and thence through the Nelson River to Hudson Bay. The average level of the Lake of the Woods during the years 1892–1915, under a state of control, has been 1059.7, sea-level datum.

Under natural conditions there were two main outlets to the Lake of the Woods. The larger of these, known as the Western Outlet, is that in which the present Norman Dam is located. The present Kenora Municipal Power Plant is constructed in what is termed the Eastern Outlet. For a Key Map showing the various outlets, see Plate 19.

So far as we have been able to ascertain, the outlets of the Lake of the Woods remained in their natural condition until 1879. In that year a head race was constructed partially in earth and rock excavation, and partially in timber structure, in a depression at the extreme westerly end of Portage Bay, Keewatin. This depression had theretofore acted as a small overflow channel for the Lake at high stages. In about 1885 the intake was further deepened. The power developed at this site was used, during certain seasons of each year, until 1906, for the operation of a saw and planing mill. Since that time the entire plant has been closed.

The extreme northerly portion of the Lake of the Woods, at Portage Bay, is separated from the Winnipeg River, at Darlington Bay, by a natural rock ridge along which now runs the Canadian Pacific Railway. Even at a comparatively early date it appears to have appealed to several persons that the waters of the Lake might, by means of artificially constructed channels, be carried across this natural barrier and used for power development.

In 1881 a small cut was made through the rock ridge at the location of the present Mill "C" head race, and power developed for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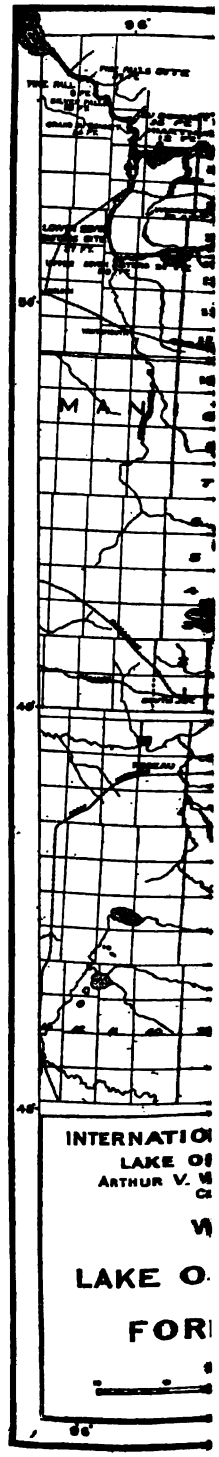

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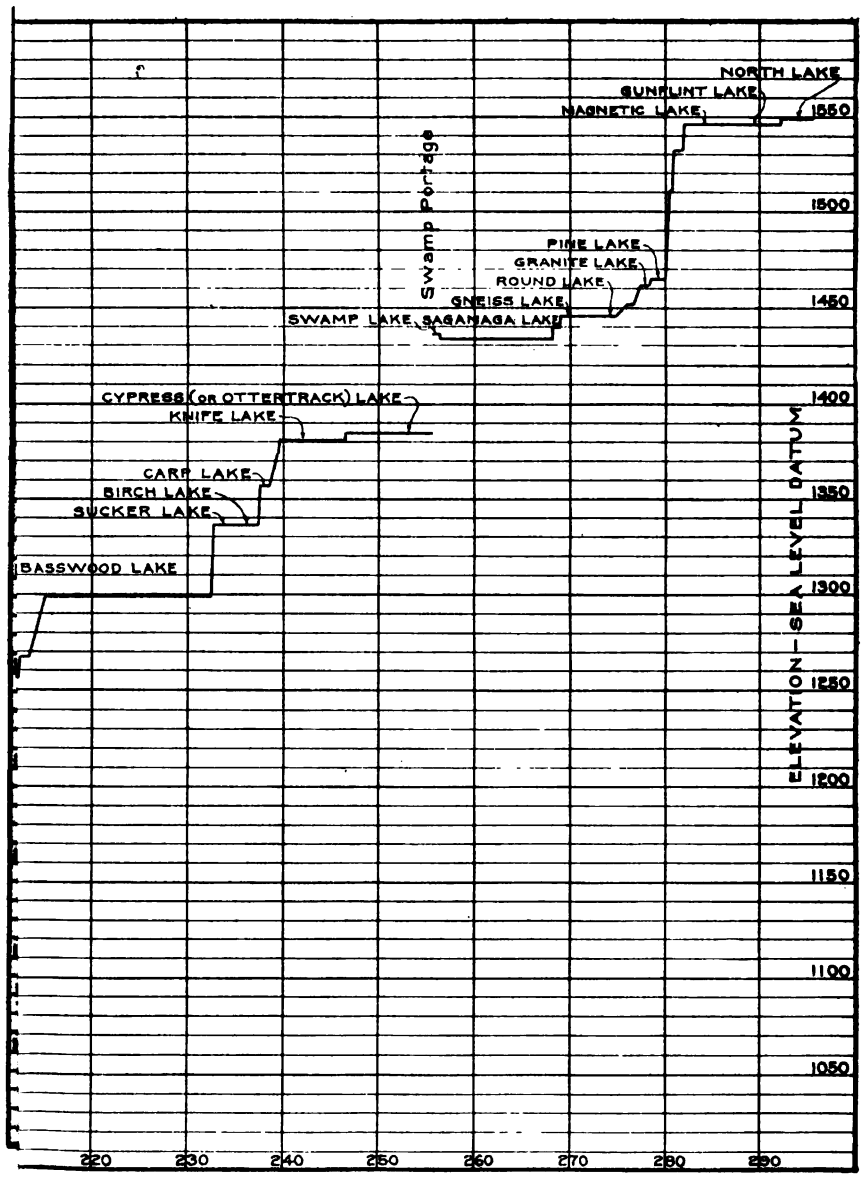

NORTH LAKE
GUNFLINT LAKE
MAGNETIC LAKE
Swamp Portage
PINE LAKE
GRANITE LAKE
ROUND LAKE
GNEISS LAKE
SWAMP LAKE
SAGANAGA LAKE
CYPRESS (or OTTERTRACK) LAKE
KNIFE LAKE
CARP LAKE
BIRCH LAKE
SUCKER LAKE
BASSWOOD LAKE
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
ELEVATION — SEA LEVEL DATUM
220
230
240
250
260
270
280
290

operating a saw mill. This site changed hands several times during the succeeding years, eventually becoming the property of the Lake of the Woods Milling Company about the year 1906, and now constitutes the site of what is known as Mill "C."

Between Portage Bay and the Western Outlet there is a small inlet which formerly merged into a low area of muskeg extending northward from the Lake of the Woods almost across the rock ridge lying between the Lake and the Winnipeg River.

The Canadian Pacific Railway has constructed its main line across the head of this bay. The tracks were originally supported by trestle work, which was later replaced by a fill. About 1878, a breakwater, consisting of rock-filled timber cribs, was built on the lakeward side of the trestle, to confine and protect the proposed fill.

Certain parties holding land between the Railway and the Winnipeg River apparently entertained the hope that water might seep through the breakwater, and the stone foundation of the trestle, in sufficient quantity to operate a small mill on the shore of the River below. Consequently, about 1882 or 1883, these parties undertook to make a small excavation across the narrow divide between the Lake and the River, with the object of developing power. Apparently the project was abandoned. Subsequently the Railway Company completed its solid fill where the trestle formerly stood.

About the year 1889, other parties appear to have acquired the land to the north of the Railway, and a small power house (since destroyed) was erected on the shore of the Winnipeg River, even though there was no water to operate such a plant. The interested parties then commenced legal proceedings against the Canadian Pacific Railway Company, contending that the Company had spoiled a natural power site by the fill on its right of way. The action was dismissed on the ground that the contentions of the claimants could not be justified. This project was then also abandoned.

In 1887 a canal, several hundred feet west of the first cut, was excavated by the Lake of the Woods Milling Company, for the purpose of developing power for flour milling at what is now Mill "A."

In the winter of 1887 to 1888, a structure known as the Rollerway Dam—and which acted essentially as a submerged weir—was constructed in the Western Outlet of the Lake of the Woods. The location of this dam is shown on Plate 19. The circumstances which resulted in the construction of this Dam, according to the best information we have been able to obtain, are as follows:

In the early eighties there prevailed a period of exceptionally low water on the Lake of the Woods watershed (see Plate 11). This low water had adversely affected navigation, milling and other interests on the Lake of the Woods—more particularly in the vicinity of Rat Portage where settlement was then increasing. Certain interests

of "Rat Portage, Keewatin, and the Lake of the Woods" which had been suffering by reason of the low water, transmitted to the Minister of Public Works, Canada, a Memorial dated October 7th, 1884, drawing attention to the fact that:

"The water of the Lake of the Woods, during the past few years, has been gradually decreasing, and is now so low that the lumbering and other manufacturing interests are seriously interfered with, and the general business and prosperity of the place is retarded."

Suggestion was made to the effect that the outlets of the Lake of the Woods near Rat Portage might be dammed so as to raise the level of the Lake, thereby removing the difficulties due to low stage, and at the same time rendering more valuable the water power possibilities existent at the outlets of the Lake.

The low water was evidently a matter of considerable public concern. Mr. A. D. McQuarrie, who subsequently was placed in charge of the Norman Dam at the time the Ontario Government assumed control, stated to Mr. A. V. White, in the summer of 1913, in substance, that in the early eighties he (Mr. McQuarrie) was Editor of a small newspaper known as *The Rat Portage Progress*, and that, at that time, the low water period was producing a marked adverse effect on the navigation of the Lake and on the milling interests near Rat Portage; and, further, that through his newspaper, representations were made showing the public need for adopting some means of preventing the Lake from dropping to such low water stages. Persons prominently identified with the development of the Lake of the Woods country endeavoured to secure Government assistance to hold the levels of the lake at more advantageous stages. Among such persons was Mr. John Mather, himself a pioneer and largely interested in lumbering and milling operations on the Lake.

On the 5th of April, 1887, an Order-in-Council was passed by the Dominion of Canada, in which it is stated that Mr. John Mather, who, with others, had been urging the necessity for the construction of a dam, had offered to undertake the erection of a suitable structure, provided that assistance to the amount of $7000 be furnished by the Government. The Order-in-Council recites that:

"The Minister states that the Chief Engineer of his Department reports that the objects for which the construction of the dam is sought, are:

"(*a*) To maintain the water of the Lake of the Woods at a constant level and thus permit the shallow draft steamers, which have been built for the navigation of the lake to ply during the whole of the season of navigation and thus afford uninterrupted connection between the settlements around the Lake and the C. P. Ry. and,

"(*b*) To maintain a constant head of water for the mills, both saw and grist, which have been and hereafter may be erected, and which depend for their power and therefore their constant working upon an ample supply of water, which would be given were the proposed dam constructed."

PLATE B

Courtesy of Manitoba Hydrographic Survey

NORMAN DAM UNDER CONSTRUCTION—JUNE 30, 1894

Courtesy of Manitoba Hydrographic Survey

NORMAN DAM UNDER CONSTRUCTION—NOVEMBER 2, 1894

Subsequently, on the 23rd of June, 1887, the Parliament of Canada voted $7000 towards the construction of the proposed dam. The Rollerway Dam was constructed in the Western Outlet in the winter of 1887 to 1888, and after its completion the sum previously voted was paid to the proper parties.

It appears that the work on the dam was performed with local labor according to the design, instructions and under the direction of Mr. John Mather. No records of plans or specifications have been found.

When Mr. A. F. Naff of the General Land Office, Washington, D. C.—and who is again referred to below—visited the site of the Rollerway Dam, about the end of November, 1895, the dam was still in place, although apparently "the top part had been washed away." Mr. Naff states:

"At Rat Portage I found the dam, that was built by the Canadian Government across the Western outlet of the lake, in the year 1888, still intact with the exception, that, at a high stage of the water sometime, the top part had been washed away, but still leaving enough in place to hold the water up some three feet above what the normal level of the lake would be under natural conditions. This statement you will notice is corroborated, to some extent, by the statements made in the affidavits taken at Rat Portage and herewith attached."*

From such enquiries as we have been able to make, it appears that it was the intention of those erecting the Rollerway Dam, to have the low water level permanently raised thereby to the extent of about 3 feet. Some statements bearing upon this point, appear in the affidavits secured by Mr. Naff, and given in Appendix I.

The Rollerway Dam finally was removed by blasting in 1899. Reference to our Plate No. 29 will show that some portions of the old dam are still in evidence.

In 1892 a small power plant was constructed in the Eastern Outlet of the Lake of the Woods, by the Citizens Telephone & Electric Light Company, but the natural outflow through this outlet of the Lake did not really come under control until the construction of the present Kenora Municipal Power Plant in 1906.

Between 1893 and 1895, a dam consisting of two sets of masonry piers and sluices, joined by a rock fill, and known as the "Norman Dam," was constructed in the Western Outlet of the Lake about a mile below the old Rollerway Dam. The Norman Dam did not effectively control the passage of water through this outlet until a considerable number of stop-logs were placed in the sluices in 1898, in which year the Ontario Government entered into an agreement with the owners of the dam,—The Keewatin Power Company, Limited—to operate the dam "for the purpose of improving the navigation of the said Lake."

* For copies of affidavits see Appendix I, page 257.

In consequence of these various changes at the outlets of the Lake, and more particularly as the result of the construction of the two dams in the Western Outlet, the subject of the levels of the Lake of the Woods first came prominently to public attention in the United States in 1895, when Mr. A. F. Naff, Special Agent of the United States General Land Office, was sent to investigate the flooding of lands on the southerly shore of the Lake of the Woods, alleged to have resulted from the construction and maintenance of the dams in the outlets of the Lake.

The Report of Mr. Naff appears in this Report as Appendix 1. The essence of Mr. Naff's report is, that the stage then prevailing was "an abnormal one and the source of much dissatisfaction"; and further, that the Lake at the time of his examination was being held up "some three feet above what the normal level of the Lake would be under natural conditions."

Apparently no action was taken by the United States Government as the result of this investigation by Mr. Naff.

With the opening up of the country surrounding Rainy Lake and the Lake of the Woods, navigation became a prominent factor in the commercial development of the district adjacent to the Lake of the Woods on both sides of the boundary.

The mining boom in Ontario increased the water borne traffic very considerably. Navigation on the Lake of the Woods centered largely around Rat Portage, now Kenora.

In 1900 the United States Army engineers were authorized, by Congress, to report upon the practicability of the creation of a suitable harbor on the south shore of the Lake.

At that time, according to the report* of the Engineer who made the investigation:

"Warroad itself consists of a few temporary buildings, occupied by two saloons, a barber shop, a restaurant, a general store, and a hotel. The land has been lately opened for settlement, which, under the 'homestead law,' must be occupied five years before a deed can be obtained."

The district officer, Major Frederic V. Abbot, in his report of June 21st, 1900, to the Chief of Engineers, U. S. A., states:

"On the American side of the Lake the country is as yet a wilderness, consisting almost entirely of Indian reservation, portions of which only have been thrown open to settlement. Warroad is one of these localities thus opened."

And further:

"The entire Canadian shore is said to be reasonably well settled and with a number of points at which boats can land in safety * * *.

"The commerce of the Lake is very considerable, being carried in some eight steamers, some of them drawing as much as 7 feet of water, loaded."

* Examination of Warroad Harbor and Warroad River, Minnesota, House Document No. 92, 56th Congress, 2nd Session, Washington, D. C., 1900. 6 pp. Map and Plate. See Appendix A, Final Public Hearings, Levels of the Lake of the Woods, January and February, 1916.

WARROAD HARBOR SHOWING UNITED STATES DREDGE

Courtesy of Mr. T. C. Mills and Manitoba Hydrographic Survey

HIGHWAY BRIDGE AND OLD ROLLERWAY DAM (BUILT IN 1887) IN WESTERN OUTLET OF LAKE OF THE WOODS—PHOTO IN 1889

Courtesy of Dr. N. Schnarr and Manitoba Hydrographic Survey

ANOTHER VIEW OF HIGHWAY BRIDGE AND ROLLERWAY DAM

PLATE D

STEAMER "KEENORA" IN DEVILS GAP NEAR KENORA, ONTARIO

MOTOR BOAT PARADE AT KENORA, ONTARIO

AMONG THE REEDS—NORTH WEST ANGLE INLET

Mr. C. W. Raynor, the engineer who made the examination on the ground, drew attention to the navigation interests of the district in the following terms:

"Rat Portage, on the north shore of the Lake of the Woods, has hitherto controlled the bulk of the commerce on the Lake and Rainy River, supplying the region from Winnipeg * * *.

"Warroad River affords the only natural harbor on the American side of the Lake, and, if open to a navigable depth, would transfer the bulk of this commerce to Warroad, which is 12 miles nearer Winnipeg and in a direct line with the Rainy Lake region. * * *

"The people of this region are unanimously desirous of having the necessary work done to make Warroad River accessible to all boats plying on the Lake of the Woods, of which there are over 100 engaged in commerce and pleasure, and of which the maximum draft is 8 feet.

"Warroad, with a navigable harbor and the railroads, has, by its location, every prospect of becoming a place of several thousand inhabitants and of carrying on much of the trade which at present falls to the Canadians."

In order to obtain a navigable harbor such as it was believed would develop navigation and enable successful competition to be carried on for some of the existent Canadian trade, the District Officer recommended that a 7 foot channel, at a lake stage of 7.2 on the Warroad gauge, or 1060.8 sea-level datum, be dredged across the bar at the entrance to Warroad River.

The project as recommended and approved by the Chief of Engineers and the Secretary of War, was passed by Congress, and $45,000 appropriated for executing the work.

After the United States Government had created the Warroad Harbor, it was found that the level of the Lake of the Woods was falling lower than the assumed 7.2 stage.

In May, 1905, the United States Secretary of War wrote to the United States Secretary of State requesting that an arrangement be entered into with the British Government, by which a dam across the outlet of the Lake of the Woods, which was under the control of the Provincial Government of Ontario, and by means of which the level of the Lake could, to some extent, be regulated, should be so operated as to prevent the level of the Lake from falling below the datum of 7.2 feet on the Warroad gauge.*

In its communication of May 6th, 1905, to the British Embassy at Washington, D. C., the United States Department of State, writes, respecting Warroad Harbor, as follows:

"The Improvement depends very largely upon the level of the Lake of the Woods, all the estimates for dredging the harbor and its approaches being based upon the maintenance of this level at or above the datum of 7.2 feet on the Warroad Harbor gauge."

The recommendation of the United States Chief of Engineers was eventually brought to the attention of the Public Works Department, Ontario. This Department had, in the year 1898, undertaken,

* For Diplomatic Correspondence, see Appendix C, Final Public Hearings, Levels of the Lake of the Woods, January and February, 1916. Compare also Appendix A.

by an agreement with the Keewatin Power Company, Limited, to operate the Norman Dam in the interests of navigation.

Commenting upon the action taken by the Ontario Government at the time the recommendation of the United States Chief of Engineers was under consideration, Mr. R. P. Fairbairn, the Deputy Minister of Public Works, Ontario, and who was Chief Engineer of that Department at the time, states:*

"In 1906, there was brought to the attention of this Department, a recommendation made by the United States Chief of Engineers, War Department, that the level of the Lake of the Woods be not permitted to fall below a stage of 7.2 on the Warroad gauge. This 7.2 was taken to be approximately an equivalent of 100.90 on the gauge which the Public Works Department had established in the vicinity of Kenora. In making this request, the Chief of Engineers pointed out that there were several water power companies at or near the dam, which would be benefited by the maintenance of the Lake at the highest possible datum.

"After giving this matter consideration, it was decided that the 7.2 asked for as a *minimum* stage, was too high because it would not make provision for the handling of the flood water without causing stages at certain seasons of the year to be much higher than this 7.2. I was Chief Engineer of the Department of Public Works at that time, and reported that a *minimum* stage of 7.2 would not be in the interest of all parties concerned, and that the interests of navigation, both in Canada and the United States, could no doubt be served by keeping the level of the Lake in the near vicinity of from 100 to 101 on the gauge at Kenora. Consequently, in the interests of navigation, as conducted by both the United States and Canada, as nearly as possible what may be called a general stage, instead of a *minimum* stage, of 7.2 has been maintained."

As a result of high water during the summer of 1905, numerous protests were received by the United States Department of State, from settlers on the southerly shore of the Lake of the Woods, complaining of damage to their land from high water. No immediate action was taken. Further complaints were made to the Department, and on February 1st, 1908, the United States Secretary of State requested, from the Secretary of War, information respecting the relation between 7.2 feet on the Warroad gauge and "the normal level of the lake under natural conditions." This request was referred to the District Officer of the Corps of Engineers, U. S. A., at St. Paul, Minnesota. The investigation of the District Office was apparently confined largely to an examination of the records of the Warroad gauge, with the conclusion that "the mean level of the lake, during the open seasons of these six years (1899, 1903, 1904, 1905, 1906, and 1907) has been 7.15 feet"; that there was "nothing unusual" in the stage which prevailed during the preceding year; and that this stage was "due to natural causes." Upon further inquiry being made by the Chief of Engineers, the District Officer reported that no records were available from which the level of the Lake, before the construction of the Rat Portage (Norman) Dam, could be determined. Apparently, no further action was taken at that time.†

* See Appendix V; also pages 435 and 523, Final Public Hearings, Levels of the Lake of the Woods, January and February, 1916.

† For additional Departmental correspondence see *infra*, Appendix VI, page 270.

PLATE E

BEST FARM BUILDINGS ON SOUTH SHORE—1913

DRIFTWOOD ON FLAX STUBBLE (ELEVATION 1081.5) WASHED IN DURING STORM OF JUNE 5, 1913

FIELD OF BARLEY ON AUGUST 18TH, WHERE DUCKS SWAM AFTER STORM OF JUNE 5TH, 1913

During the exceptionally low water season, early in 1911, the channel at Warroad proved to be of insufficient depth to permit of navigation by a few of the deeper draft boats plying on the Lake of the Woods. In consequence, protests against the low water were sent by citizens of Warroad to the United States War Department, urging the deepening of the channel. The matter was referred to the District Officer of the Corps of Engineers, U. S. A., at St. Paul, Minnesota, who, in a letter dated June 9th, 1911, reported against the necessary deepening of the channel, largely for the reason that it could not be done under the existing project for the improvement of Warroad Harbor, as authorized by the Congress of the United States. He further reported the stage then prevailing to be "very unusual," and stated that it was probably the result of control of the outflow from the Lake. He further stated:*

"It would be perfectly possible by proper works at the outlet to maintain a good depth of water in the Lake of the Woods at all times. In this particular, however, the interests of navigation and those of power development are directly opposed, the one requiring constant level and very variable discharge and the other a constant discharge with greatly varying fluctuations in lake level. It is my belief that the Canadian Government has decided for the latter alternative; intends to develop power at the outlet and has made its channel [referring to the mouth of Rainy River] sufficiently deep to offset the bad effects of fluctuations of lake level. It is certainly to be recommended that this matter be brought to the attention of the International Joint Commission."

On June 27th, 1912, as an outgrowth of this recommendation, the three questions relating to the regulation of the level of the Lake of the Woods, and the utilization of the waters of that Lake and of the tributary waters, contained in the Official Reference, previously quoted, were submitted to the International Joint Commission by the Governments of the United States and of the Dominion of Canada, under the provisions of Article IX of the Treaty of January 11th, 1909, between Great Britain and the United States.

During July and August, 1912, the authors of this Report were employed individually as Engineers, one for each section of the Commission, for the purpose of making a preliminary canvass of the situation, with the object of determining what data were available for use in formulating a reply to the questions of the Official Reference. It soon became apparent, however, that considerable field work would be required before sufficient physical data would be in hand for the purpose of preparing the necessary reply. In consequence, outlines of procedure for the collection of essential data were at once prepared. In September 1912, preliminary Hearings were held, by your Commission, at International Falls, Minnesota, at Warroad, Minnesota, and at Kenora, Ontario, for the purpose of securing testimony which would aid your Engineers in prosecuting the investigation

*See Appendices A and C Final Public Hearings, Levels of the Lake of the Woods ,January and February, 1916.

along lines calculated to yield your Commission as large a fund of information as possible, bearing directly on the questions in hand.

Immediately after the completion of the Hearings, on October 1st, 1912, the authors of this Report were appointed as Consulting Engineers to your Commission, and such modifications in plans and methods of procedure as were indicated by the testimony of the Public Hearings were adopted; the collection of data was continued, field operations were planned in considerable detail, and arrangements consummated providing for the coöperation of various Departments of Government, of both the Dominion of Canada and of the United States, of the State of Minnesota, and of the Province of Ontario, by which physical data, which were then being gathered, or which would be collected in the future, by these various Departments, would, as as soon as practicable, be made available for the use of your Consulting Engineers. It may here be added that some of these preliminary agreements later were supplemented, and provision made to the effect that certain special information to be gathered primarily for the use of the International Joint Commission, and at the specific request of your Consulting Engineers, would be paid for, at least in part, by your Commission. It is a pleasure to state that, on the whole, these arrangements have proved highly satisfactory. They have prevented a duplication of effort, and have placed us in command of a large body of physical data, the collection of which, by our own staff, would have prolonged the preparation of this Report, and have entailed large additional outlays.

In concluding this introductory statement, we desire to express our obligation and deep appreciation to the many Departments of both Governments, as well as to corporations and individuals, who have so generously rendered valuable assistance from time to time throughout the prosecution of this investigation. Among these are:

The International Boundary Commission, United States and Canada.

The Manitoba Hydrographic Survey, Dominion Water Power Branch, Department of the Interior, Canada.

The Geological Survey, United States Department of the Interior.

The Department of Public Works, Canada.

The Corps of Engineers, United States Department of War.

The Commission of Conservation, Canada.

The United States Coast and Geodetic Survey.

The Geodetic Survey of Canada.

The Geological Survey of Canada.

The General Land Office, United States Department of the Interior.

The Geographer's Branch, Department of the Interior, Canada.

The United States Department of State.

The Department of Railways and Canals, Canada.
The Department of Indian Affairs, Canada.
The Printing Department and Engraving Branch, Ottawa.
The Government Printing Office, Washington.
The Topographical Surveys Branch, Department of the Interior, Canada.
The Weather Bureau, United States Department of Agriculture.
The Meteorological Service, Department of Marine and Fisheries, Canada.
The State University of Minnesota.
The Department of Public Works, Ontario.
The Minnesota State Forest Service.
The Supervisor of the Superior National Forest.
The Ontario Hydro-Electric Power Commission.
The State Drainage Commission of Minnesota.
The Department of Lands, Forests and Mines, Ontario.
The Towns of Fort Frances, International Falls, Kenora, and Warroad.
The Greater Winnipeg Water District.
The Minnesota & Ontario Power Company.
The Keewatin Power Company, Limited.
The Lake of the Woods Milling Company, Limited.
The Minnesota Canal & Power Company.
The St. Croix Lumber & Manufacturing Company.

The Commission, as before intimated, is also much indebted to many individuals who have contributed data, photographs, etc. In presenting copies of these various data, etc., effort has been made, in the Tables and elsewhere, to acknowledge the sources of the information.

The present occasion is a fitting one for us to express our very hearty appreciation of the helpful attitude of your Commission. It will be recalled that, after the investigation had progressed to certain stages, it was recognized that the scope of the inquiry must necessarily be extended in order to secure additional detailed data essential to an adequate consideration of the Official Reference. In consequence of this fact, the time originally deemed sufficient for the inquiry has had to be extended. We desire, therefore, to acknowledge here the latitude you have given us, coupled, as it has been, with your support and encouragement.

We desire to make special mention of the unfailing interest, consideration, and valuable assistance received from the two Commissioners delegated by you to supervise the Lake of the Woods Investigation,—Mr. Charles A. Magrath and Mr. James A. Tawney.

We desire, further, to express our appreciation of the services of our many assistants, without whose loyal support satisfactory progress could not have been made. Among those deserving of special mention are our principal Office Engineer, Mr. George M. Shepard, C. E., of Minneapolis, Minn.; and our Chiefs of Field Staffs, Mr. J. L. Rannie, D. T. S., of Ottawa, Canada, and Mr. George M. Garen, C. E., of Stillwater, Minn.

We desire also to give recognition to the engineering work of Mr. Gordon S. Stairs, Mr. Arthur Welin, and Mr. C. J. Vick; to the drafting work of Mr. John Hall and Mr. L. R. Graham; and to the clerical work of Miss M. L. Chandler and Miss E. I. Gilby.

To those unfamiliar with the detailed instructions under which this investigation has been prosecuted by your Consulting Engineers, we desire to add that everything in the nature of final conclusions or recommendations has been purposely omitted from this Report, in order to allow your Commission the fullest latitude in preparing your reply to the questions of the Official Reference.

Your Commission, on October 3rd, 1912, it will be recalled, requested that the data presented by the engineers "be so full and complete that the Commission may have liberty of choice."

FIELD OPERATIONS

NEED FOR PHYSICAL DATA

The first question of the Official Reference deals with the practicability and the desirability of regulating the level of the Lake of the Woods, in order to secure the most advantageous use of the waters of that Lake, and of the waters flowing into and from the Lake, together with the advantageous use of the shores and harbors of the Lake.

The second question is anticipative, and deals with the extent to which low lands bordering the shore of the Lake would be flooded in case certain recommended levels, higher than the normal or natural level of the Lake, were maintained; and the value of the land which would be submerged under those conditions.

The third question deals with the manner in which such regulation, as might be recommended, could be best secured and maintained with the least possible damage to all rights and interests affected.

It is apparent that the answers to these questions must be found, primarily, in physical data, consequently we will first call attention to the various field operations by means of which data, bearing upon these questions, were collected since the institution of this investigation, both by our own field staff and through coöperation with the various Departments of both Governments, and with the interests involved.

OPERATIONS BY FIELD STAFF OF THE INTERNATIONAL JOINT COMMISSION

Field operations prosecuted by our own staff of engineers and assistants along the southerly shore of the Lake of the Woods, consisted of detailed topographic and hydrographic surveys covering the entire shoreline of the Lake of the Woods, from the Northwest Angle Inlet to Big Grassy River; and in addition, surveys of portions of Shoal Lake, Big Island, Bigsby Island, and other smaller islands lying near the southerly shore of the Lake. These surveys were made by transit and planetable. The work was coördinated by means of our own tertiary triangulation system, which was in turn based on the secondary triangulation system of the International Boundary Commission. (For map showing triangulation net see Atlas.) The results of these surveys are shown on the maps constituting Sheets 1 to 25 and Key Map assembled in the Atlas accompanying this Report. These maps show topographic features by 1 and 2 foot contour intervals, between the contours of 1054 and 1064–1066* sea-level datum,

*The Lake of the Woods survey does not embrace all of the area lying between the 1064 and 1066 contours. Between these contours certain parcels of land were discovered upon portions of which some actual improvement, such as clearing or cultivation, had been made. Between the 1064 and 1066 contours, only the parcels which include the improved portions above mentioned, have been surveyed.

and on a scale of 1 to 24,000 or 2,000 feet to the inch. A total area of 139 square miles is contoured. Of this area 31.5 square miles represent water area, and 107.5 square miles represent land area. Of the land area 1.1 square miles represent cultivated land; 3.1 square miles represent grass land; about 1 square mile represents sand or outcrops of rock; 41.6 square miles are covered by deciduous or coniferous trees, varying in size from pole wood to merchantable timber; 14.0 square miles are covered with willows and other small brush; and 45.2 square miles represent open marsh or bog, most of which, at the time the survey was made, was floating.

It will be apparent from an inspection of the maps constituting Sheets 1 to 25 of the Atlas, that a large portion of the field work had to be performed under trying conditions, the surveyors being required to wade in water for days at a time. In the low lying areas the summer pests of flies, mosquitoes, etc., were very bad.

Field operations prosecuted by our engineers and assistants in the northerly portion of the Lake of the Woods, consisted, primarily, of a reconnaissance examination and sketching, with the aid of pocket compass and hand level, of the smaller, isolated, low areas not surveyed by the transit and planetable parties operating in the southerly portion of the Lake. The portion of the Lake covered by these reconnaissance examinations is characterized by high bluff shores, enclosing here and there small areas of low land bordering bays and inlets. Usually these areas, consisting mainly of marsh and bog, were quite flat, and were bordered on the one side by water, and on the other by high rocky ridges. On the field sketches were drawn the 1063 contour and the water's edge, the latter being at an elevation of approximately 1060, and, so far as it could be readily determined by sounding and by noting the margin of vegetation, the 1058 contour was also located and drawn. In addition, information was noted with respect to the character of the land, vegetal cover, improvements, etc.

The sketches resulting from this examination are shown on Reconnaissance Sheets 1 to 3 and Key Map of the Atlas.

A summary of the reconnaissanced areas of the northerly portion of the Lake of the Woods follows:

Between Contours	Timbered Land All Kinds	Grass, Brush, Marsh, Water	Total Area * Acres
1058 and 1060.	.....	2221.8	2221.8
1060 and 1063.	733.5	3897.6	4631.1
1058 and 1063.	733.5	6119.4	6852.9

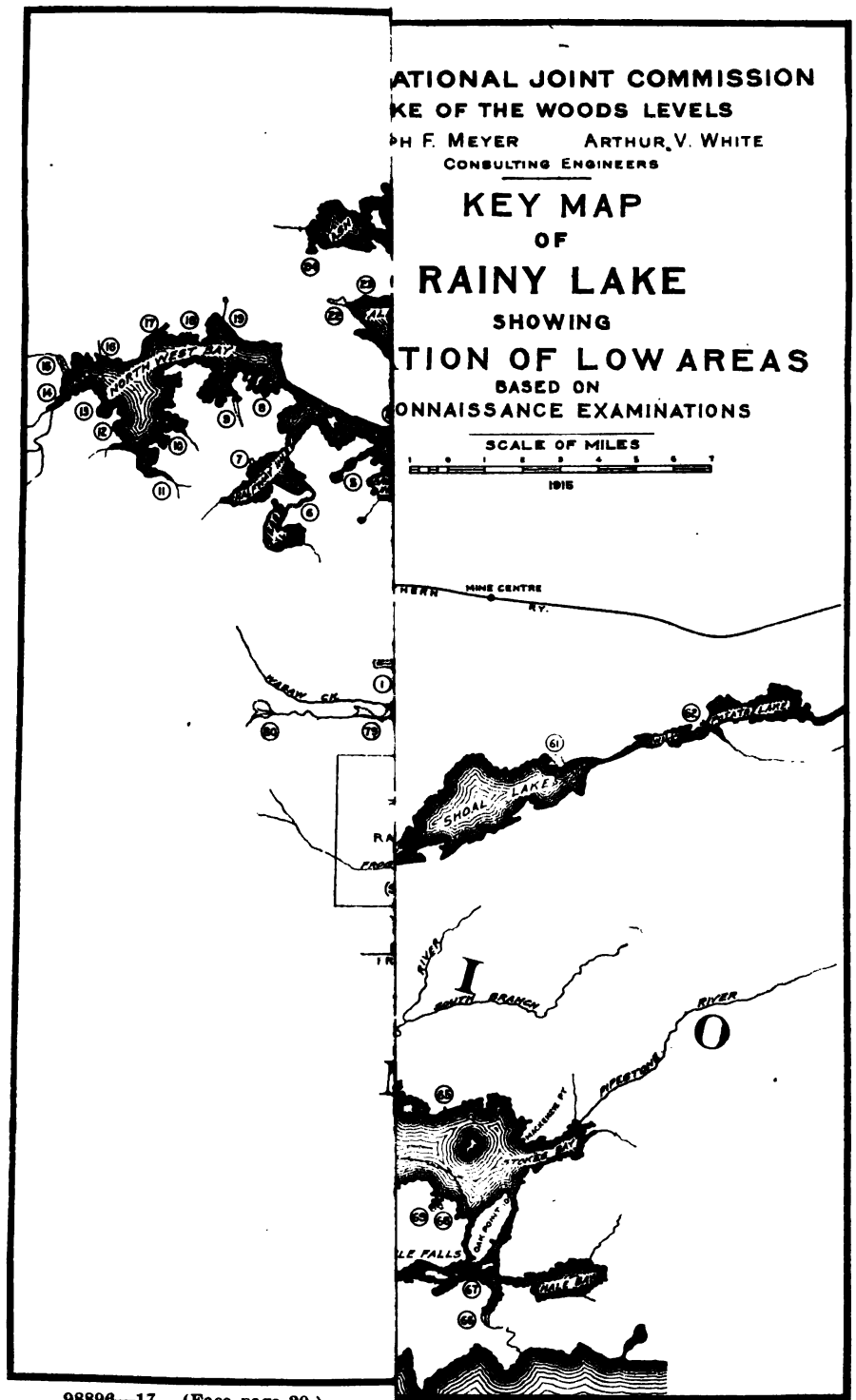
* Regarding interpretation of significant figures see page 47.

Field operations prosecuted by our own engineers and assistants on Rainy Lake consisted, principally, of a reconnaissance examination of the entire shoreline of the Lake, for the purpose of ascertaining the location of low lands which would be subject to overflow in case the Lake should be raised to provide additional storage, and to determine the approximate extent of such flowage. The location of low areas is indicated by numbers on the accompanying Key Map, and a brief description based on the reconnaissance examination is given below for each numbered area.

Number	Description
1	Low area at portage, widening out to about half a mile, extending across neck of peninsula between high rock bluffs, and connecting with another low area about 800 feet in width, bordering small creek and marsh, and then narrowing down to about 100 feet at north end of portage. Covered with small timber.
2	100 to 200 feet wide, ¾ mile long around end of bay. Small timber.
3	100 to 200 feet wide, 1 mile long around end of marshy bay. Small timber.
4	200 to 300 feet wide, extending for nearly a mile around bay. Small timber.
5	200 to 300 feet wide, extending around bay and up creek around marsh. Small area at mouth of creek covered with burnt timber, also narrow strip along shore to west.
6	100 to 200 foot strips extending ½ mile up both sides of creek from Halfway Inlet to Wegg Lake. Small timber.
7	Area about 600 ft. x 800 ft. at south end of portage. Small timber.
8	Narrow strip along south side of bay 50 to 100 feet wide, ½ mile long. Small timber.
9	Area about 300 feet by ¾ mile at north end of portage. Small pine and spruce.
10	Low area at mouth of small creek 200 ft. x 1100 ft. Small pine.
11	Low areas at south end of Northwest Bay, 400 ft. x 2000 ft., covered with pine, and spruce. Narrow strip of sand on south side. Banks caving.
12	Low area 100 to 150 feet wide, across points between three small bays, leaving points practically islands. Low area also extends along shore of each bay. Width of this strip about 150 feet, and total length about ½ mile. Small poplar.
13	Low area at back of small marshy bay. 600 ft. x 2200 ft. Covered with tamarack and poplar.
14	Several small areas along extreme west side of Northwest Bay, 100 feet wide and 1½ miles long. Also two small areas at mouths of small creeks emptying into bay. Tamarack, poplar, and a few pine.
15	About 500 feet wide each side, extending about ½ mile up creek. Small poplar.
16	Low area at south end of portage, 1000 feet by ½ mile. Small poplar. Indian log cabin 14 ft. x 16 ft. about 2.5 ft. above Lake. Water Level 497.3.
17	Small low area just east of mouth of creek, with 2 Indian log cabins 14 ft. x 18 ft. and 16 ft. x 20 ft.
18	Two Indian log cabins 14 ft. x 16 ft. on small low areas in I. R. 17.
19	Low area around small marshy creek, 350 feet wide, about 900 feet long. Small poplar and pine.
20	Low strip just east of portage, 700 feet wide and about ½ mile long. East margin of strip runs around point of Alexandria Bay. Covered with small poplar.
21	Low strip about 700 feet wide, extending north-easterly from Northwest Bay to marsh, and thence north to tamarack swamp. Small poplar and scattered tamarack.
22	On extreme west side of Alexandria Bay is a narrow marsh running back about ½ mile. Low area of varying width extends entirely around this marsh and is covered with small poplar, and some pine.

98896—17——3

Number	Description
23	Area 400 ft. x 1500 ft. Small poplar and birch.
24	About 200 to 300 feet wide and 2000 feet long, extending around small bay, in west end of Ash Bay. Small poplar and pine.
25	Low area at mouth of small creek, 300 to 400 feet wide and about ¼ mile long. Small poplar and pine.
26	At north end of Manitou Sound is abandoned camp about 3 feet above Lake. 3 buildings of little value. Water Level 497.3
27	Small low area about half mile below head of Manitou Sound. 3 log cabins and ice house, about 3 feet above Lake. Owned by S. H. Baldwin. Water Level 497.3
28	Strip of land about ¼ mile wide and ¾ mile long, bordering small bay just north of mouth of Little Canoe River. Marsh and small poplar and spruce.
29	Strips 250 feet wide, extending about 2 miles up both sides of Little Canoe River. Small poplar, spruce, and jack-pine.
30	Small poplar over narrow strip extending about a mile up both sides of small creek.
31	Border of small poplar, birch, and jack-pine, extending about 1½ miles along shore. Width up to 150 feet.
32	Low area 200 feet wide, 2 miles long. Small poplar and birch with a few patches of small pine.
33	Narrow strip about 1800 feet long, widening out in places to about 300 feet. Small poplar.
34	Frog Portage (under water), Low strips about 300 feet wide and ¼ mile long on each side. Small poplar.
35	250 feet wide and about ¼ mile long, around bay. Jack-pine and small poplar.
36	Low area back of small bay, about 500 feet by 1100 feet, covered with very small poplar.
37	Low area south of bay about 2000 feet wide and ½ mile long, covered with very small birch and poplar, and a few scattered pine.
38	Lockhart sawmill. Low area here runs about 45 feet wide and 350 feet long. Entire plant including main mill is on low area.
39	Truck farm owned by H. Stone is on low strip 350 feet wide and 1000 feet long. House 12 ft. x 16 ft.
40	Narrow strip at head of bay, covered with small pine and poplar. Abandoned logging camp on this area. Sand beach at camp.
41	Strip 300 feet wide and 1½ miles long, extending around curved marsh which forms the northerly end of Rice Bay. Small poplar and a few jack-pine.
42	400 feet wide, bordering bay, 2000 feet long. Marsh, and small poplar.
43	Strips about 150 feet wide each side, extending up creek for about 1 mile. Marsh and some small poplar and scattered jack-pine.
44	Small low area on north shore of entrance to Grassy Portage Bay. R. J. Smith Fishery located on this area. 4 buildings, 10 ft. x 15 ft., 15 ft. x 20 ft., 15 ft. x 30 ft., and 20 ft. x 30 ft., 2.5 to 3.0 feet above Lake. Water Level 497.1
45	At Sims Crossing the track of the Canadian Northern Railway is 4.2 feet above present water level. Water Level 497.1
46	Smith's Fishery is located near the R. R. bridge on an Island at the entrance to Redgut Bay. There are 3 buildings about 1.5 to 3.0 feet above the lake on a low area, about 100 ft. x 132 ft. Water Level 497.0
47	Frame building 12 ft. x 16 ft. on island north of bridge. Low area about 300 ft. x 650 ft.
48	Low area at northwest end of Redgut Bay 600 feet wide, ¾ mile long. Mostly small poplar with some jack-pine and birch.
49	Strips about 200 feet wide, extending up each side small creek about 1000 ft. White pine, small poplar and jack-pine.
50	Strips about 200 feet wide by 1000 feet long, extending up each side of creek leading from Otukamamoan Lake. White pine, small poplar and jack-pine.
51	450 feet wide by about 1,000 feet long. Norway pine and poplar.
52	Logging camp owned by Rainy Lake Pulp Co. Two of the log houses are on low ground, less than 4.0 feet above lake. Water Level 497.0
53	Low area about 150 feet wide by ¾ mile long at mouth of small creek. A few scattered cedar.



98896—17. (Face page 20.)

Number	Description
54	Indian Village at mouth of Ottertail Creek, comprised of 8 log houses and 2 frame shacks, all about 12 ft. x 14 ft. All buildings except three log cabins are on low ground.
55	Canadian Northern Railway runs across northern end of Ottertail Lake. Level of Lake to base of rail 2.75 feet. Lake Level 497.0
56	Bears Pass Pumping Station, 12 ft. x 14 ft. frame building. Floor of pumping station is 3.8 feet above lake level. Water Level 497.0
57	Log house belonging to T. Wilson on low area.
58	Mr. Smith's Fishery on east shore of entrance to Redgut Bay. Three buildings, 18 ft. x 24 ft., 30 ft. x 32 ft., and 6 ft. x 6 ft., all on low area.
59	Low area about 450 ft. x 2000 ft. around bay on north side of Grassy Lake. Small poplar.
60	Low area about 300 feet wide and ¼ mile long, extending in a southwesterly direction at the extreme west end of Shoal Lake. Tamarack and small poplar.
61	Low area 1100 ft. x 1400 ft., cutting off point on north shore of Shoal Lake near its east end. Willow, balsam, pine and a few small poplar.
62	Gorman's Camp. 2 buildings 30 ft. x 30 ft. on small low area on north shore of Wild Potato Lake.
63	Strip about 800 feet wide and 1600 feet long on south shore. Scattered large white pine and tamarack and a few poplar.
64	Low area approximately 600 feet wide by ¼ mile long at eastern end of Bleak Bay. Muskeg with a few small tamarack.
65	Camp of Northern Construction Co. One building, 30 ft. x 30 ft., is on small low area.
66	Low area at mouth of Bear Creek, about 1000 feet wide and ¼ mile long, covered with willow brush and a few poplar.
67	Low island, formerly a point, occupied by Geo. Randolph, has on it a log house 18 ft. x 20 ft., three other small log cabins and three small frame shacks. Highest point on island is 3.9 feet above Lake. Water Level 496.9
68	Low area about 400 ft. x 800 ft., bordering small bay. Tamarack, spruce, and a few cedar and balsam.
69	Low area at south end of bay about 200 feet wide by 500 feet long. Poplar, spruce, tamarack and balsam.
70	Small area 60 ft. x 150 ft. on point, on north side of Saginaw Bay. Two buildings 16 ft. x 20 ft. and 16 ft. x 18 ft. owned by Harry Smith. Sand beach.
71	Low area about 800 feet wide and 3000 feet long at portage between Lost Bay and Saginaw Bay. Scattered tamarack.
72	Two small cabins both about 10 ft. x 12 ft. at water's edge at entrance to Cranberry Bay. Water Level 496.8
73	Three story log house 28 ft. x 42 ft. on west shore at entrance to Black Bay, 2.2 feet above lake level. Water Level 496.8
74	Strips from 200 to 400 feet wide, extending about 2000 feet up both sides of small creek. Small poplar and patch of hay meadow about 400 ft. x 700 ft. Also building 20 ft. x 24 ft. on west shore of bay.
75	Low area about 400 feet wide at west side of Rat Root Bay, extending westerly about 2000 feet to another small bay. Small poplar.
76	Building on west shore of small bay 16 ft. x 20 ft.
77	Low area from 200 to 400 feet wide, and about 120 rods long, about ½ of it cleared and fenced, and the remainder covered with small poplar and brush.
78	Engine and boiler rooms and spur track of Northern Construction Company on low area about 200 ft. x 600 ft.
79	Low area varying in width up to 500 feet, and extending nearly a mile up creek. Mostly willows.
80	Swamp about ½ mile across each way, covered with dense growth of willow, alder, and tamarack.

The entire shoreline of Rainy Lake was examined by reconnaissance methods, and the location, size, and shape of all low areas noted and sketched.

In addition to the low areas here described, a considerable number of minor areas, such as narrow strips along bays and inlets were noted.

Nearly all of the examinations were made while the level of Rainy Lake ranged from 497.3 to 496.8, Public Works, Canada, datum, and consideration was given only to the areas lying between the 501 contour and the lake level at the time of the reconnaissance.

The total area of the various small low areas reconnaissanced on Rainy Lake, including minor areas not shown on the Key Map, such as narrow strips along the shore, is approximately 2800 acres. Most of this land is covered with small timber.

Leaving out of consideration the plants of the Northern Construction Company, Lockhart's saw mill, the Canadian Northern Railway, and all structures on the Rainy River between the dam and the outlet of Rainy Lake, the value of buildings, shacks, etc., situated below the 501 contour is believed to be about $5000.

Following the reconnaissance examination, the larger areas were instrumentally surveyed with transit and planetable. One foot contours, between elevations 497 and 501 Public Works, Canada, datum, were, as a rule, located. A tertiary system of triangulation control, based on the secondary triangulation of the International Boundary Commission, was used. The maps resulting from these surveys are presented as Rainy Lake Sheets 1 to 4 of the Atlas.

The surveys on Rainy Lake were confined to the area between elevations 497 and 501, Public Works datum. In those places where the shores were generally steep, no surveys were made—the 497 contour and the old shoreline or margin of vegetation shown on the maps as a broken blue line being based on the instrumental surveys of the International Boundary Commission made in 1913 and 1914.

Practically all of the land lying between the old shoreline and the 497 contour is covered with willow brush. Above the 497 contour the character of the soil and the increasing slope of the ground is reflected in a rather dense growth, consisting principally of deciduous trees.

On the Rat Root River a fringe of deciduous timber, along the water's edge, is frequently backed by tamarack swamp,—a condition not uncommon, also, around the Lake of the Woods.

A summary of the surveyed areas on Rainy Lake follows:

	Cultivated Land	Grass Land	Coniferous Trees	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Water	Rock	Total* Area Acres
Elevation† 501 to 500												
U. S. A.	16.8	18.3	.....	289.9	133.1	362.9	20.5	.....	.....	.....	.....	841.5
Canada	4.2	5.4	.....	5.3	105.1	17.5	2.4	1.5	.....	.....	9.8	151.2
Total	21.0	23.7	.....	295.2	238.2	380.4	22.9	1.5	.....	.....	9.8	992.7
Elevation 500 to 499												
U. S. A.	7.3	12.9	.....	247.2	163.7	505.8	20.0	24.3	.....	.....	.....	981.2
Canada	4.7	4.4	.....	8.9	81.2	23.5	1.5	1.2	.....	.....	4.3	129.7
Total	12.0	17.3	.....	256.1	244.9	529.3	21.5	25.5	.....	.....	4.3	1110.9
Elevation 499 to 498												
U. S. A.	9.1	16.4	.....	298.2	144.7	471.0	41.8	48.7	.....	.....	.....	1029.9
Canada	0.8	3.0	.....	13.8	80.7	19.7	2.9	2.7	.....	.....	5.7	129.3
Total	9.9	19.4	.....	312.0	225.4	490.7	44.7	51.4	.....	.....	5.7	1159.2
Elevation 498 to 497												
U. S. A.	7.0	13.9	.....	335.9	151.8	359.4	249.7	86.8	.....	.....	.....	1204.5
Canada	0.3	3.3	.....	28.6	73.5	17.6	3.7	6.0	.....	.....	6.3	139.3
Total	7.3	17.2	.....	364.5	225.3	377.0	253.4	92.8	.....	.....	6.3	1343.8
Elevation 497 to Old Shore Line												
U. S. A.	3.9	15.6	.....	632.2	101.5	152.7	3712.7	637.0	.....	.....	.....	5255.6
Canada	.....	2.5	.....	127.3	71.3	9.5	369.2	311.0	.....	.....	4.0	894.8
Total	3.9	18.1	.....	759.5	172.8	162.2	4081.9	948.0	.....	.....	4.0	6150.4
Elevation 501 to Old Shore Line												
U. S. A.	44.1	77.1	.....	1803.4	694.8	1851.8	4044.7	796.8	.....	.....	.....	9312.7
Canada	10.0	18.6	.....	183.9	411.8	87.8	379.7	322.4	.....	.....	30.1	1444.3
Total	54.1	95.7	.....	1987.3	1106.6	1939.6	4424.4	1119.2	.....	.....	30.1	10757.0

* Regarding interpretation of significant figures see page 47.
† Elevations refer to Department of Public Works, Canada, Datum.

Field operations prosecuted by our own engineers and assistants on the lakes above Kettle Falls consist of planetable and transit surveys, supplemented by reconnaissance examinations with pocket compass and hand level, of the shores of Lake Namakan, Kabetogama, Sand Point, Crane, Little Vermilion, and a number of smaller, immediately tributary, lakes. The maps resulting from these surveys constitute Kettle Falls Sheets 1 to 4 of the Atlas. Wherever the topography is shown by solid contour lines on these maps, the

surveys were made with the planetable. Wherever the topography is shown by broken contour lines, a reconnaissance examination was made with pocket compass and hand level. In all localities where instrumental surveys were made, the shoreline shown was traversed, and represents the well defined line of medium high water, as indicated by the margin of land vegetation at the time of the survey. The elevation of this shoreline was approximately 505. Extreme high water marks, however, as shown by the lichen growth on the rocks, are at an elevation of 509 to 510 Public Works datum, or about 1121 sea-level datum.

The shoreline on the United States side, where no planetable surveys were made, was taken from the township maps of the United States General Land Office. The shoreline on the Canadian side, where no planetable surveys were made, was taken from the various Canadian maps, or run out by magnetic chain traverse. As part of the surveys were carried on during the winter low water period, it was possible to locate contours below the elevation of 505. There are, in places, considerable areas of marsh below this elevation over portions of which wild hay is sometimes cut during seasons of low water.

A few soundings were taken in the channels connecting the various lakes, to indicate approximately what the lowest stage would be to which these lakes could be drawn down. (For maps of interconnecting channels see Atlas.)

A summary of the areas above Kettle Falls is given in the following table:

	Cultivated Land	Grass Land	Coniferous Trees	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Water	Rock	Total* Area Acres
Elevation 505 to 510												
U. S. A.	.....	20.5	1000.0	1285.5	.....	1158.0	624.5	383.0	.....	.....	.....	4471.5
Canada	.....	65.5	257.0	510.0	.....	79.5	377.5	22.0	.....	.....	.....	1311.5
Total	.....	86.0	1257.0	1795.5	.....	1237.5	1002.0	405.0	.....	.....	.....	5783.0
Water's Edge† to Elevation‡ 505												
U. S. A.	.....	625.0	.....	.....	.....	321.0	843.5	1470.5	.....	.....	.....	3260.0
Canada	.....	227.0	.....	42.5	.....	52.5	264.0	211.5	.....	.....	.....	797.5
Total	.....	852.0	.....	42.5	.....	373.5	1107.5	1682.0	.....	.....	.....	4057.5
Water's Edge† to Elevation 510												
U. S. A.	.....	645.5	1000.0	1285.5	.....	1479.0	1468.0	1853.5	.....	.....	.....	7731.5
Canada	.....	292.5	257.0	552.5	.....	132.0	641.5	233.5	.....	.....	.....	2109.0
Total	.....	938.0	1257.0	1838.0	.....	1611.0	2109.5	2087.0	.....	.....	.....	9840.5

* Regarding interpretation of significant figures see page 47.
† Water's edge at time of survey. Elevation given on maps.
‡ Elevations refer to Department of Public Works, Canada, Datum.

On the basis of partial surveys of the areas between the 510 and the 515 contours, it would appear that there are from 6,000 to 8,000 acres of land between these contours.

In addition to the surveys just referred to, our field parties established a number of temporary gauges on the Lake of the Woods which were read for portions of the two years during which field operations were in progress. Some gauge readings were also secured through the employment of the gauge readers of the International Boundary Commission, during periods for which the Boundary Commission did not require records.

OPERATIONS BY FIELD STAFF OF THE MANITOBA HYDROGRAPHIC SURVEY

Field operations prosecuted by The Manitoba Hydrographic Survey, Dominion Water Power Branch, Department of the Interior, Canada, consisted of:

1. Topographic and hydrographic surveys of the various outlets of the Lake of the Woods and their interconnecting channels, and portions of the Winnipeg River below the outlets of the Lake.

2. The collection of a large number of gauge readings, and the making of discharge measurements which will be referred to in detail later.

3. A survey of boat houses, docks, and other improvements in the vicinity of Kenora.

4. The collection of invaluable photographs and historical material of an engineering character, much of which was secured principally through the zealous activities of Mr. Stuart S. Scovil.

ADDITIONAL FIELD OPERATIONS

Field operations prosecuted by the International Boundary Commission, which were of particular benefit to the International Joint Commission, consisted mainly of secondary triangulation, covering the southerly portion of the Lake of the Woods and parts of Rainy Lake, records of lake stages at Warroad, Oak Island, and Oak Point, and surveys of the upper lakes along the International Boundary.

Field operations prosecuted in pursuance of a coöperative agreement between the International Joint Commission and the Department of Public Works, Canada, consisted of surveys of portions of the Rainy River at Pithers Rapids, at Long Sault Rapids, and at Manitou Rapids.

In addition to the data resulting from our own field operations and those performed by various departments of both governments under coöperative agreements, all physical data which were being gathered on the watershed, particularly by the Manitoba Hydro-

graphic Survey, the United States Geological Survey, and the Department of Public Works, Canada, were made available for the use of the International Joint Commission prior to their publication. In this way a very considerable amount of time was gained, and all necessity for duplication of activities prevented.

Besides the various field operations heretofore mentioned, we have, ourselves, examined all of the boundary waters tributary to the Lake of the Woods, from the divide between North Lake and South Lake to the source of the Winnipeg River, and several of the larger lakes in Minnesota indirectly tributary to the Lake of the Woods.

In coöperation with the United States Geological Survey, a gauging station with automatic recording gauge was established and maintained on the Kawishiwi River, near Winton, Minnesota. A gauge was also established and maintained on the Rainy River at the foot of Long Sault Rapids and another on Lake Vermilion at Tower, Minnesota.

In coöperation with the State Forester of Minnesota, and the Supervisor of the Superior National Forest, data were secured relating to the construction and operation of logging dams on the Minnesota portion of the watershed of the Lake of the Woods.

In addition to the maps of the Atlas already referred to, a map is presented showing the entire watershed of the Lake of the Woods. This map was compiled from the best available sources of information, and includes the results of our own surveys, and the surveys of the boundary waters above Kettle Falls, made by the International Boundary Commission.

Small scale maps of the outlets of the Lake of the Woods, portions of the Winnipeg River, Pithers Rapids, Koochiching Falls in a state of nature, Manitou Rapids, Long Sault Rapids, and other small maps are presented in the volume of Plates.

SCOPE OF SURVEYS

In commencing our field work in 1913, we had the great advantage of being able to control our survey by the secondary triangulation system laid out by the International Boundary Commission.

Topographic signals were set by our engineers to form a tertiary system of triangulation, which in turn was coördinated with the secondary triangulation system of the Boundary Commission.

Between topographic stations azimuth stadia traverses were run to constitute a control for the planetable surveys employed to obtain the topography. These traverses, between ties made to the triangulation points, were, on an average, four or five miles in length.

The survey of the southerly shore of the Lake of the Woods was commenced in 1913 with Warroad, Minnesota, as the first base.

In that year the survey extended from an east and west line two miles north of the International Boundary, near Buffalo Point, in the Province of Manitoba, south and east along the southerly shore, through the State of Minnesota, to a point in the Province of Ontario about three miles east of Rainy River.

The field work, in 1914, comprised the survey of the low lying country between the Northwest Angle Inlet and Buffalo Point, where the 1913 surveys had commenced. Surveys east of Rainy River were extended to the neighborhood of Big Grassy River—this being practically the eastern boundary of the larger areas of low lying lands. Surveys were also made of certain low areas on Big and Bigsby Islands, and on the shores of Shoal Lake.

Field operations, both in 1913 and in 1914, commenced about the end of May and terminated in the early part of October.

On September 1st, 1914, a portion of the survey equipment and party was transferred to Rainy Lake, where surveys were made in the vicinity of Black Bay, Rat Root River, Cranberry Bay, Stanjikoming Bay, and Little Ottertail Lake. This party was disbanded at Fort Frances on October 12th, 1914.

FIELD METHODS

The International Joint Commission maps show elevations above sea-level by brown contour lines. A contour, as is known, is a line all points on which are of the same elevation. The locations of these contours were determined by survey methods best adapted to the respective topographic peculiarities of each district. The methods, in general, were about as follows: At intervals of from 1500 to 2000 feet, dependent on the character of the country, main traverse lines were run approximately perpendicular to the direction of the shoreline, and along these traverse lines elevations were taken, from which to determine the contours. Elevations were also taken at distances of from 300 to 700 feet on either side of the main traverse lines so that in thus working back and forth along these main lines the territory under consideration was well covered.

The method of survey adopted was determined mainly by two considerations; first, by the uniformity of the slope, and second, by the character of the surface of the land, i. e., whether it was firm, open or timbered land, or marsh and floating bog. Obviously, fewer elevations were required to be taken over areas where the slope was so uniform as to permit the contours to be interpolated with the required precision. In rougher and more broken country the frequent changes in slope necessitated the taking of elevations at close intervals. In general it is estimated that on the Lake of the Woods survey the average interval between shots was from 500 to 800 feet. This indicates the flat and uniformly sloping character of the greater portion of this district.

The taking of topography is, of course, easiest on firm open ground where the breaks in slope are visible and choice of the critical topographical features is readily made. The major portion of the topography was taken with planetables. This method permitted the platting, in the field, of elevations, contours and other topographic features. Wherever a transit was used, field sketches were made, in addition to the notes, showing the more important topography.

On firm ground, so covered with timber and brush that the topographical features were not discernible by inspection, a great deal of axe work was necessary. Throughout country of this character readings were taken on what appeared to be the mean ground surface, especial care being taken to avoid humps or hollows.

Throughout the large areas of open marsh and bog, the problem of ascertaining the topography is largely a question of good judgment on the part of the rodman in putting into intelligent practice the instructions of his topographer. Where a more or less solid subsoil is overlain with a foot or more of spongy moss, into which anyone, while standing, might sink about a foot, the rod was pressed firmly down into the moss.

In taking elevations on floating bog, the character of which will later be described, the rod was pushed down through the floating surface mat or sod by a sudden pressure of from 10 to 50 pounds, depending on the toughness of the sod, until the rod reached the firmer bottom below the underlying muck or ooze. The rod was then raised up by an amount equal to what the rodman, from his experience in pushing the rod downwards, had estimated the thickness of the floating sod to be. The elevation thus obtained was recorded as representing approximately what the elevation of the surface of the bog would be if the water were drained off so as to allow the floating sod to settle down on firm bottom. On the Lake of the Woods survey it was found that, generally speaking, contours could be determined with a sufficient degree of accuracy by taking lines of levels across the bog at intervals of 1000 to 1500 feet.

At the edge of much of the floating bog the shoreline exists as a well defined, reasonably firm ridge, cast up by the waves. A characteristic portion of such a shoreline is shown on Plate H. The cast-up material consists mainly of vegetable matter broken up by the waves, intermingled with driftwood, sand, and clay, and supporting the growth of an occasional dwarf shrub.

Along other portions of the southerly shore of the Lake of the Woods, the floating bog is continually being broken up by the waves and carried away, partly finely divided, and partly as large floating islands that do much damage to the pond net fishermen. Such a shoreline with its "islands" is shown on Plate F.

PLATE F

INDEFINITE SHORELINE AT EDGE OF FLOATING BOG OR MUSKEG—STONEY POINT

TYPICAL "ISLAND" OF MUSKEG ANCHORED BY POUND NET

PLATE G

1 & 2. SURVEYING FLOATING BOG—LAKE OF THE WOODS

3. SETTING TOPOGRAPHIC SIGNAL

4. RODMAN GIVING "SHOT" IN OPEN MARSH OR BOG AT LANDWARD EDGE OF CAST-UP SHORELINE

5. RUNNING TRANSIT LINE THROUGH MARSH AND BRUSH

Back of the ridge of cast-up material, constituting the shoreline at the edge of much of the floating bog, there is an area which rises and falls with changes in lake level. This area consists of peat vegetation usually a foot or more in thickness, floating on a watery muck or partly decomposed roots, from 1 to 2 feet to occasionally as high as 5 or 6 feet above the firmer subsoil.

The character of the floating bog and of the shoreline at the edge of the bog necessitated special methods of surveying. The manner of representing the information secured by the surveys, and particularly that relating to floating bog, is significantly stated in the following note which appears on all of the Lake of the Woods Sheets.

Land areas bordering the shore of the Lake and subject to overflow at a lake stage of 1060 are shown in a light blue tint. The portions of such overflowed areas which are shown traversed by broken line contours usually represent floating bog whose surface rises and falls with changes in lake stage. These broken line contours represent, approximately, what the elevation of the surface would be if, at lower lake stages, the floating bog settled down on its firmer subsoil.

The full blue shoreline represents either high banks or a ridge of material cast up by the waves at the edge of floating bogs. The shoreline in long blue dashes represents the irregular and less well defined edge of floating bog not marked by a ridge of cast up material. The shoreline in short blue dashes represents a conventional shoreline or water's edge, at a lake stage of 1058, in those bays and inlets where physical evidences of a definite shoreline were, for the most part, indistinguishable.

COMMENTS ON EARLY CHARACTER OF SHORE

Some of the outstanding physical features characterizing the shoreline of the Lake of the Woods have not been due to forces operating only during recent years, but on the contrary, these physical features are manifestations which are to be expected at all times on the shores of a lake such as the Lake of the Woods.

In order to give an idea of the appearance of the shores, particularly the southern and western shores, of the Lake of the Woods, before this region was settled, the following statements are taken from the Report of the British North American Boundary Commission on the "Geology and Resources of the Region in the Vicinity of the Forty-Ninth Parallel", by George M. Dawson, Assoc. R. S. M., F. G. S., Geologist and Botanist to the Commission. These statements are based on field work performed during the years 1873 and 1874.

"The southern and larger part of the lake, properly called 'Sandhill Lake', washes bare Laurentian rocks along its northern edge, while the whole of its southern and southwestern margin is formed of sand and detrital matter, and sweeps around in large, gently rounded bays, very different to the narrow irregular passages of the north. This southern portion of the lake is also comparatively shallow, and perpetually extending its bordef southward and westward, among the swamps, sandhills and lagoons by which it is there surrounded and spreading detritus thus attained over its bed. Evidence of this is everywhere apparent along its southern margin, where tamarack swamps are in some places being so rapidly encroached on that the trees may be seen along the shore bending forward at every angle and falling into the lake. Some

parts of the shore have, in this way, become surrounded by an almost impassable belt of tangled and water-worn trunks and branches. The water of the southern part of the lake is turbid from the wash of the waves on the soft shores and matter brought down by Rainy River; giving rise to a formation of deposits of sand and clay now going over the greater part of its bed. * * *

"The greater part of the southern and western margins of the lake is utterly useless, and a more forbidding and desolate region can scarcely be imagined. The immediate border of the lake, is here formed by a low ridge of sand often blown into miniature sandhills, but sometimes bound together by the roots of various grasses. Behind this margin is very generally a stretch of grassy swamp and lagoon of a mile or two in width and bordered in the distance by a forest of tamarack growing on a scarcely less flooded soil. In some places low, swampy, savannah fronts directly on the lake, and this I have seen fringed, after a gale, by a belt many feet in width of brown vegetable pulp equally impassable to walk on and impassable for a canoe. On other parts of the coast, on gaining the summit of a peat bank a few feet in height, which is breaking off under the action of the waves, an expanse of swamp with dead tamarack trees, stretches as far as the eye can reach. * * *

"Many of the less deeply submerged swamps would yield large quantities of natural hay. Those in the vicinity of the North-west Angle are already made to furnish hay for the stock kept there, which though rather coarse, it is found to be nutritious. * * *

"The climate of the region immediately bordering on the Lake of the Woods, is much improved by it. The shallow expanse of water becomes heated by the rays of the sun, and in July and August was very generally found to have a temperature of from 70° to 75° Fahrenheit. Early frosts are thus prevented, and the nights, which at a like elevation on the prairie west of Red River are frequently cold, are here, as a rule, deliciously balmy. Should land for agricultural purposes ever become of value in this region, a great area of the bottom of the lake might be laid dry, at comparatively small expense, by removing the rocky barrier at Rat Portage, the water being thus lowered about eighteen feet."

PROVINCIAL AND STATE LAND SURVEY SYSTEMS

The Lake of the Woods surveys, comprising, as they do, portions of the Provinces of Ontario and Manitoba and of the State of Minnesota, include areas which have been surveyed according to the Government Land Survey systems employed in both countries.

The land survey systems of the State of Minnesota and of the Province of Manitoba are not greatly dissimilar. In each case the lands have been laid out in quadrilateral townships, approximately six miles square, containing 36 sections, each of which has an area of 1 square mile or 640 acres, more or less, dependent on the usual meridional and other corrections. The lines bounding a township on the east and west sides are true meridians and those on the north and south sides are chords of the parallels of latitude passing through the corners of the townships.

The townships are numbered in regular order northerly from some parallel of latitude or base line, and lie in Ranges which are numbered, in general, east or west from certain initial meridian lines styled First, Second, Third, etc., Meridians according to their position with respect to some Principal Meridian.

PLATE H

CHARACTERISTIC CAST-UP SHORELINE AT EDGE OF FLOATING BOG
LAKE OF THE WOODS

DETAIL OF CAST-UP SHORELINE SHOWING VEGETABLE FIBER BROKEN UP BY
WAVE ACTION

For ready reference and comparison it is well, at this point, to draw attention to the most important differences between the systems of survey in Minnesota and Manitoba.

The accompanying diagrams show the arrangement of sections, order of numbering, road allowances, etc., for townships in Minnesota, Ontario, and Manitoba.

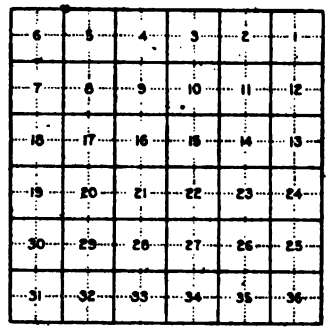


DIAGRAM OF A STANDARD TOWNSHIP IN MINNESOTA

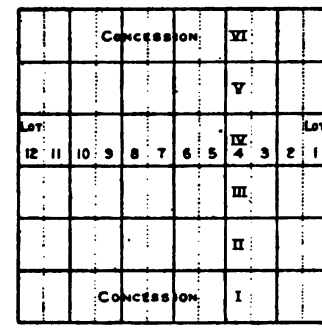


DIAGRAM OF A NORMAL TOWNSHIP IN ONTARIO

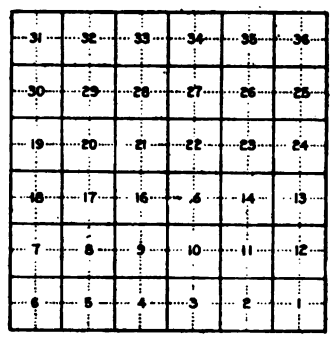
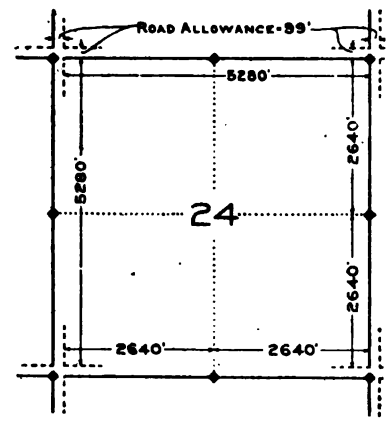


DIAGRAM OF A STANDARD TOWNSHIP IN MANITOBA



DETAIL OF A STANDARD SECTION IN MANITOBA

In Manitoba there is a road allowance of 1½ chains, or 99 feet, around each section of one square mile.

In Minnesota no road allowance whatever has been made, and wherever roads follow along section lines half the width of the road lies in one section and half in the other. In consequence of this, a township in Manitoba is six road allowances, or 594 feet, wider than a township in Minnesota.

Under both systems of survey the sections of a township are subdivided into four quarter sections of 160 acres (more or less) each.

Lands in Ontario, lying in the vicinity of Lake of the Woods, are also laid off into quadrilateral townships approximately six miles square. This rule, however, is sometimes altered to suit the irregularities of the shoreline, some irregular townships being as much as nine miles in one direction and eight miles in the other.

The lines bounding a township on the east and west sides are true meridians, six miles apart on the south boundaries, while those on the north and south sides are chords of the parallel of latitude passing through the corners of the township.

The townships are named, in place of being numbered as in the case of Minnesota and Manitoba.

No road allowances are actually laid out in this system of survey, but 5 per cent of the land is reserved by the Crown for roads.

The township is laid off by east and west lines, one mile apart, into concessions numbered from the south towards the north. Section lines are run astronomically, north and south, from points one mile apart on the southern township boundary. Posts, bisecting the north and south boundaries of each section, mark the division of the section into two lots.

In order to explain certain apparent discrepancies in land lines on the International Joint Commission survey maps for portions of Minnesota territory, it is necessary to point out that the position of many of the lines and corners established by the original land surveys is in error; and also, that in certain cases the bearings and distances as obtained from the field notes of the land surveyors are inconsistent with the actual location of the corners. On the other hand, it was found that complete reliance could be placed on the land surveys in Canadian territory.

In Manitoba the township, section and quarter corners are, in general, marked by iron posts and by pyramidal mounds of earth or stone, and four pits. In Minnesota wooden posts, referenced by blazes on near-by trees, styled "bearing trees," are used to mark the corners. These may easily be destroyed by fire and the corners thus lost.

In Manitoba it is compulsory that the surveyor clear his lines and use a transit instrument for the determination of directions. The survey is made astronomically within very small specified limits of error.

In Minnesota less reliance has been placed on astronomical control, and the directions of the lines have, to some extent, been determined by the magnetic compass—a method, which, while quicker, is less accurate than astronomical determinations.

Several cases have been noticed, in the Lake of the Woods territory, where the bearings given by the United States Land Survey plats were in error by as much as one degree or more. Also, in one

instance, in platting a line across a township according to bearings and distances shown on these plats, an error of 300 feet has been disclosed by means of the triangulation of the International Joint Commission surveys.

The effects of local attraction on the magnetic needle is more especially noticeable in the Minnesota Survey of the Rainy Lake district. Here the direction of the section lines becomes at times very erratic, and one instance may be noted, where, on platting a section according to the distances given for the four sides, the closing line of the square did not close on the initial point by over 300 feet.

With respect to fence locations it may be commented, that, in several places, for example, in Sections 20, 33 and 34 of Township 163 N., Range 36 W. of the 5th Meridian, Sheet No. 10, it will be noted that there are fences which properly belong, and no doubt are intended to follow, on the section and quarter lines, but which on the maps are not thus represented. The reason for this may be due to either one or both of the following circumstances:

First, the fences may not have been built where they properly belong with respect to the legal surveyed lines of the section, so that their location on the land is in error.

Second, the fences may be properly located with respect to the monuments determining the legal lines of the section, but due to the inability of the International Joint Commission surveyors to find certain of the original monuments, the section lines, as projected on the maps according to the field notes of the Land Office surveys, may not, in such cases, be legally correct.

METHOD OF MEASURING SURVEYED AREAS

The areas between the various contours shown on the maps of the Atlas were measured, by means of planimeters, on the original manuscript maps which were drawn to a scale of 1000 feet to 1 inch. Areas were obtained between the different contours for each different culture classification, such as deciduous trees, willows and brush, open marsh or bog, etc. The boundaries between the different kinds of culture growth are much more definitely marked on the original manuscript maps than they are on the final maps which are printed in colors and on the reduced scale of 2000 feet to 1 inch.

To insure perfect adjustment of the instruments, the planimeters—which were of both the rolling and the polar types—were tested twice daily by means of a test circle having a standard graduated steel bar for a radius. The peculiarities of the instruments were carefully observed and each was tested in various positions so that, as far as possible, all errors due to lost motion, etc., were avoided in the measurement of the areas. For example, it was observed that the rolling

planimeters gave less accurate results with the tracing arm at right angles to the rollers, consequently, especial care was taken, as far as practicable, to make all measurements with this arm at smaller angles with the rollers. It was also found very essential to give the instruments a thorough cleaning about once every four days.

In measuring the areas two complete sets of readings were taken by observers working independently of each other, and a high degree of accuracy was required. The allowable differences between any two corresponding determinations varied with the size of the areas measured.

The total area in each township, between the various contours, was first determined. Then the area, in each section, between the same contours, was determined, and the several quantities adjusted slightly so as to make their sum equal the total area previously determined for the entire township. Lastly the areas between contours, as subdivided according to the culture classifications, were determined for each section, and these quantities were in turn adjusted to equal the total area previously determined for the given section.

SURVEYED AREA BETWEEN CONTOURS—SHEETS 1-19

(SOUTHERLY SHORE)

	Area in United States and Canada		Area in United States		Area in Canada		Area in United States and Canada		Area in United States		Area in Canada	
	Acres	Per Cent of Total Area	Acres	Per Cent	Acres	Per Cent	Acres	Per Cent of Total Area	Acres	Per Cent	Acres	Per Cent
	1066 to 1064*						1060 to 1059					
Cultivated land	344.2	13.0	315.7	91.7	28.5	8.3						
Grass land	225.8	8.5	177.6	78.7	48.2	21.3	31.2	0.5			31.2	100.0
Grass land with scattered poplar	317.2	12.0	312.0	98.4	5.2	1.6	92.9	1.4	88.8	95.6	4.1	4.4
Deciduous trees	1606.5	60.7	1373.4	85.5	233.1	14.5	65.9	1.0	61.0	92.6	4.9	7.4
Mixed deciduous and coniferous	30.2	1.2	9.7	32.1	20.5	67.9	1.6		1.6	100.0		
Coniferous swamp	85.6	3.2	85.6	100.0			0.2		0.2	100.0		
Willows and brush	1.6	0.1			1.6	100.0	1535.6	23.7	1115.5	72.6	420.1	27.4
Open marsh or bog	9.6	0.4	9.6	100.0			4253.8	65.6	2433.7	57.2	1820.1	42.8
Sand	24.8	0.9	11.0	44.4	13.8	55.6	9.0	0.1	3.4	37.8	5.6	62.2
Water							495.5	7.7	63.3	12.8	432.2	87.2
Rock												
Total area	2645.5	100.0	2294.6	86.7	350.9	13.3	6485.7	100.0	3767.5	58.1	2718.2	41.9
	1064 to 1062						1059 to 1058					
Cultivated land	257.3	1.6	203.1	78.9	54.2	21.1						
Grass land	537.1	3.2	263.6	49.1	273.5	50.9						
Grass land with scattered poplar	389.9	2.4	308.8	79.2	81.1	20.8						
Deciduous trees	5037.5	30.4	3254.9	64.6	1782.6	35.4						
Mixed deciduous and coniferous	1332.5	8.0	289.5	21.7	1043.0	78.3						
Coniferous swamp	6604.4	39.8	3811.8	57.7	2792.6	42.3						
Willows and brush	666.9	4.0	303.6	45.5	363.3	54.5	370.0	5.7	272.6	73.7	97.4	26.3
Open marsh or bog	1616.9	9.8	32.4	2.0	1584.5	98.0	4535.5	70.0	2177.1	48.0	2358.4	52.0
Sand	123.4	0.7	74.8	60.6	48.6	39.4	2.5		1.2	48.0	1.3	52.0
Water							1576.0	24.3	860.8	54.6	715.2	45.4
Rock	9.6	0.1	4.8	50.0	4.8	50.0						
Total area	16575.5	100.0	8547.3	51.5	8028.2	48.5	6484.0	100.0	3311.7	51.1	3172.3	48.9
	1062 to 1061						1058 to 1056					
Cultivated land	64.2	0.7	51.6	80.4	12.6	19.6						
Grass land	515.2	5.7	318.4	61.8	196.8	38.2						
Grass land with scattered poplar	177.3	2.0	151.3	85.3	26.0	14.7						
Deciduous trees	1674.2	18.4	1168.8	69.8	505.4	30.2						
Mixed deciduous and coniferous	328.5	3.6	84.7	25.8	243.8	74.2						
Coniferous swamp	2117.3	23.3	1517.7	71.7	599.6	28.3	4.7				4.7	100.0
Willows and brush	1787.2	19.7	661.4	37.0	1125.8	63.0	110.7	1.1	94.5	85.4	16.2	14.6
Open marsh or bog	2274.9	25.0	383.1	16.8	1891.8	83.2	4972.7	47.8	3326.7	66.9	1646.0	33.1
Sand	140.6	1.5	99.2	70.6	41.4	29.4						
Water							5326.8	51.1	2911.0	54.6	2415.8	45.4
Rock	3.7	0.1	1.9	51.4	1.8	48.6						
Total area	9083.1	100.0	4438.1	48.9	4645.0	51.1	10414.9	100.0	6332.2	60.8	4082.7	39.2
	1061 to 1060						1056 to 1054					
Cultivated land	20.4	0.2	20.4	100.0								
Grass land	506.7	5.5	430.9	85.0	75.8	15.0						
Grass land with scattered poplar	112.3	1.2	96.1	85.6	16.2	14.4						
Deciduous trees	392.1	4.3	315.5	80.5	76.6	19.5						
Mixed deciduous and coniferous	46.8	0.5	29.0	62.0	17.8	38.0						
Coniferous swamp	123.7	1.4	97.5	78.8	26.2	21.2	0.5				0.5	100.0
Willows and brush	2615.3	28.7	1371.1	52.4	1244.2	47.6	0.8		0.5	62.5	0.3	37.5
Open marsh or bog	5143.0	56.4	1624.9	31.6	3518.1	68.4	572.2	6.3	435.2	76.1	137.0	23.9
Sand	164.3	1.8	99.8	60.7	64.5	39.3						
Water							8578.7	93.7	5075.2	59.2	3503.5	40.8
Rock	0.3		0.3	100.0								
Total area	9124.9	100.0	4085.5	44.8	5039.4	55.2	9152.2	100.0	5510.9	60.2	3641.3	39.8

* The Lake of the Woods Survey does not embrace all the area lying between the 1064 and 1066 contours. Between these contours certain parcels of land were discovered upon portions of which some actual improvement, such as clearing or cultivation, had been made. Between the 1064 and 1066 contours only the parcels which include the improved portions above mentioned have been surveyed.

SURVEYED AREAS BETWEEN CONTOURS—SHEETS 20-22

(BIG ISLAND AND BIGSBY ISLAND)

	Area in United States and Canada		Area in United States		Area in Canada		Area in United States and Canada		Area in United States		Area in Canada	
	Acres	Per Cent of Total Area	Acres	Per Cent	Acres	Per Cent	Acres	Per Cent of Total Area	Acres	Per Cen	Acres	Per Cent
	1064 to 1062						59 to 1058					
Cultivated land												
Grass land	22.1	0.6			22.1							
Grass land with scattered poplar												
Deciduous trees	496.3	13.6			496.3							
Mixed deciduous and coniferous	443.2	12.1			443.2							
Coniferous swamp	2545.4	69.5			2545.4							
Willows and brush	63.6	1.7			63.6		78.7	10.3			78.7	
Open marsh or bog	68.5	1.9			68.5		406.5	53.3			406.5	
Sand	21.2	0.6			21.2							
Water							277.4	36.4			277.4	
Rock	0.7				0.7							
Total area	3661.0	100.0			3661.0		762.6	100.0			762.6	
	1062 to 1061						1058 to 1056					
Cultivated land												
Grass land	19.6	0.9			19.6							
Grass land with scattered poplar												
Deciduous trees	145.6	6.5			145.6							
Mixed deciduous and coniferous	62.8	2.8			62.8							
Coniferous swamp	967.0	43.3			967.0							
Willows and brush	412.5	18.5			412.5		20.6	1.5			20.6	
Open marsh or bog	570.7	25.6			570.7		355.3	25.5			355.3	
Sand	53.7	2.4			53.7							
Water							1015.9	73.0			1015.9	
Rock												
Total area	2231.9	100.0			2231.9		1391.8	100.0			1391.8	
	1061 to 1060						1056 to 1054					
Cultivated land												
Grass land	4.9	0.4			4.9							
Grass land with scattered poplar												
Deciduous trees	6.1	0.5			6.1							
Mixed deciduous and coniferous	2.8	0.2			2.8							
Coniferous swamp	58.1	4.3			58.1							
Willows and brush	327.7	24.5			327.7		0.4				0.4	
Open marsh or bog	922.5	69.0			922.5		47.7	3.9			47.7	
Sand	14.0	1.1			14.0							
Water							1174.8	96.1			1174.8	
Rock	0.5				0.5							
Total area	1336.6	100.0			1336.6		1222.9	100.0			1222.9	
	1060 to 1059											
Cultivated land												
Grass land	0.1				0.1							
Grass land with scattered poplar												
Deciduous trees												
Mixed deciduous and coniferous												
Coniferous swamp	0.5				0.5							
Willows and brush	155.9	16.9			155.9							
Open marsh or bog	543.4	58.9			543.4							
Sand	0.4				0.4							
Water	223.0	24.2			223.0							
Rock												
Total area	923.3	100.0			923.3							

* The Lake of the Woods Survey does not embrace all the area lying between the 1064 and 1066 contours. Between these contours certain parcels of land were discovered upon portions of which some actual improvement, such as clearing or cultivation, had been made. Between the 1064 and 1066 contours only the parcels which include the improved portions above mentioned have been surveyed.

SURVEYED AREA BETWEEN CONTOURS—SHEETS 23-25

(SHOAL LAKE)

	Area in United States and Canada		Area in United States		Area in Canada		Area in United States and Canada		Area in United States		Area in Canada	
	Acres	Per Cent of Total Area	Acres	Per Cent	Acres	Per Cent	Acres	Per Cent of Total Area	Acres	Per Cent	Acres	Per Cent
	1066 to 1064 *						1060 to 1059					
Cultivated land	0.3	12.5			0.3							
Grass land												
Grass land with scattered poplar												
Deciduous trees							0.8	0.1			0.8	
Mixed deciduous and coniferous	2.1	87.5			2.1							
Coniferous swamp							7.7	1.1			7.7	
Willows and brush							67.0	9.4			67.0	
Open marsh or bog							560.4	78.8			560.4	
Sand												
Water							75.0	10.6			75.0	
Rock												
Total area	2.4	100.0			2.4		710.9	100.0			710.9	
	1064 to 1062						1059 to 1058					
Cultivated land												
Grass land	43.6	1.6			43.6							
Grass land with scattered poplar												
Deciduous trees	391.3	14.3			391.3							
Mixed deciduous and coniferous	284.2	10.4			284.2							
Coniferous swamp	1058.7	38.7			1058.7							
Willows and brush	194.1	7.1			194.1		6.3	2.0			6.3	
Open marsh or bog	754.8	27.6			754.8		65.2	20.4			65.2	
Sand												
Water							247.5	77.6			247.5	
Rock	8.5	0.3			8.5							
Total area	2735.2	100.0			2735.2		319.0	100.0			319.0	
	1062 to 1061						1058 to 1056					
Cultivated land												
Grass land	70.0	6.0			70.0							
Grass land with scattered poplar												
Deciduous trees	126.6	10.8			126.6							
Mixed deciduous and coniferous	59.9	5.1			59.9							
Coniferous swamp	378.5	32.2			378.5							
Willows and brush	240.1	20.4			240.1		3.0	0.5			3.0	
Open marsh or bog	288.9	24.5			288.9		22.6	3.8			22.6	
Sand												
Water							573.3	95.7			573.3	
Rock	12.2	1.0			12.2							
Total area	1176.2	100.0			1176.2		598.9	100.0			598.9	
	1061 to 1060						1056 to 1054					
Cultivated land												
Grass land	9.1	0.6			9.1							
Grass land with scattered poplar												
Deciduous trees	24.1	1.7			24.1							
Mixed deciduous and coniferous	8.0	0.5			8.0							
Coniferous swamp	89.0	6.1			89.0							
Willows and brush	338.9	23.3			338.9		1.1	0.2			1.1	
Open marsh or bog	965.4	66.3			965.4		1.0	0.2			1.0	
Sand												
Water	20.6	1.4			20.6		610.8	99.6			610.8	
Rock	1.0	0.1			1.0							
Total area	1456.1	100.0			1456.1		612.9	100.0			612.9	

*The Lake of the Woods Survey does not embrace all the area lying between the 1064 and 1066 contours. Between these contours certain parcels of land were discovered upon portions of which some actual improvement, such as clearing or cultivation, had been made. Between the 1064 and the 1066 contours only the parcels which include the improved portions above mentioned have been surveyed.

TOTAL OF SURVEYED AREAS—SHEETS 1-25

UNITED STATES AND CANADA

	Cultivated Land	Grass Land	Grass Land with Scattered Poplar	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Water	Rock	Total area acres
1066 to 1064*												
Canada..	28.8	48.2	5.2	233.1	22.6	.....	1.6	.....	13.8	.....	.....	353.3
United States..	315.7	177.6	312.0	1373.4	9.7	85.6	.....	9.6	11.0	.....	.....	2294.6
Total.	344.5	225.8	317.2	1606.5	32.3	85.6	1.6	9.6	24.8	.....	.....	2647.9
1064 to 1062												
Canada..	54.2	339.2	81.1	2670.2	1770.4	6396.7	621.0	2407.8	69.8	.....	14.0	14424.4
United States..	203.1	263.6	308.8	3254.9	289.5	3811.8	303.6	32.4	74.8	.....	4.8	8547.3
Total.	257.3	602.8	389.9	5925.1	2059.9	10208.5	924.6	2440.2	144.6	.....	18.8	22971.7
1062 to 1061												
Canada..	12.6	286.4	26.0	777.6	366.5	1945.1	1778.4	2751.4	95.1	.....	14.0	8053.1
United States..	51.6	318.4	151.3	1168.8	84.7	1517.7	661.4	383.1	99.2	.....	1.9	4438.1
Total.	64.2	604.8	177.3	1946.4	451.2	3462.8	2439.8	3134.5	194.3	.....	15.9	12491.2
1061 to 1060												
Canada..	.....	89.8	16.2	106.8	28.6	173.3	1910.8	5406.0	78.5	20.6	1.5	7832.1
United States..	20.4	430.9	96.1	315.5	29.0	97.5	1371.1	1624.9	99.8	.....	0.3	4085.5
Total.	20.4	520.7	112.3	422.3	57.6	270.8	3281.9	7030.9	178.3	20.6	1.8	11917.6
1060 to 1059												
Canada..	.....	31.3	4.1	5.7	.....	8.2	643.0	2923.9	6.0	730.2	.....	4352.4
United States..	.....	.....	88.8	61.0	1.6	0.2	1115.5	2433.7	3.4	63.3	.....	3767.5
Total.	.....	31.3	92.9	66.7	1.6	8.4	1758.5	5357.6	9.4	793.5	.....	8119.9
1059 to 1058												
Canada..	.....	.....	.....	.....	.....	.....	182.4	2830.1	1.3	1240.1	.....	4253.9
United States..	.....	.....	.....	.....	.....	.....	272.6	2177.1	1.2	860.8	.....	3311.7
Total.	.....	.....	.....	.....	.....	.....	455.0	5007.2	2.5	2100.9	.....	7565.6
1058 to 1056												
Canada..	.....	.....	.....	.....	.....	4.7	39.8	2023.9	.....	4005.0	.....	6073.4
United States..	.....	.....	.....	.....	.....	.....	94.5	3326.7	.....	2911.0	.....	6332.2
Total.	.....	.....	.....	.....	.....	4.7	134.3	5350.6	.....	6916.0	.....	12405.6
1056 to 1054												
Canada..	.....	.....	.....	.....	.....	0.5	1.8	185.7	.....	5289.1	.....	5477.1
United States..	.....	.....	.....	.....	.....	.....	0.5	435.2	.....	5075.2	.....	5510.9
Total.	.....	.....	.....	.....	.....	0.5	2.3	620.9	.....	10364.3	.....	10988.0
1066 to 1054*												
Canada..	95.6	794.9	132.6	3793.4	2188.1	8528.5	5178.8	18528.8	264.5	11285.0	29.5	50819.7
United States..	590.8	1190.5	957.0	6173.6	414.5	5512.8	3819.2	10422.7	289.4	8910.3	7.0	38287.8
Total.	686.4	1985.4	1089.6	9967.0	2602.6	14041.3	8998.0	28951.5	553.9	20195.3	36.5	89107.5

* The Lake of the Woods Survey does not embrace all the area lying between the 1064 and 1066 contours. Between these contours certain parcels of land were discovered upon portions of which some actual improvement, such as clearing or cultivation, had been made. Between the 1064 and 1066 contours only the parcels which include the improved portions above mentioned have been surveyed.

SURVEYED AREAS BETWEEN CONTOURS 1058 AND 1064

BY SHEETS

Contour	Cultivated Land	Grass Land	Grass Land with Scattered Poplar	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Total Area Acres
NORTHWEST ANGLE SHEET NO. 1										
1064–63	0.9	16.4	.....	130.9	23.3	34.8	22.6	1.8	.....	230.7
1063–62	0.9	16.4	.....	130.8	23.4	34.8	22.6	1.9	.....	230.8
1062–61	.....	66.0	.....	67.1	7.1	27.7	57.9	.....	.....	225.8
1061–60	.....	.....	.....	13.1	0.8	4.1	86.9	145.7	.....	250.6
1060–59	.....	.....	.....	.....	.....	.....	37.9	173.2	.....	211.1
1059–58	.....	.....	.....	.....	.....	.....	1.3	241.1	.....	242.4
BUCKETE ISLAND SHEET NO. 2										
1064–63	0.1	25.3	.....	162.2	65.3	173.6	10.6	8.4	.....	445.5
1063–62	.....	25.3	.....	162.2	65.3	173.6	10.6	8.5	.....	445.5
1062–61	.....	18.2	.....	135.6	36.1	103.6	50.3	53.0	.....	396.8
1061–60	.....	0.3	.....	39.8	11.8	20.0	121.0	172.0	.....	364.9
1060–59	.....	.....	.....	1.1	1.6	0.2	100.4	313.4	.....	416.7
1059–58	.....	.....	.....	.....	.....	.....	25.0	378.6	.....	403.6
OAK ISLAND SHEET NO. 3										
1064–63	0.7	10.9	.....	37.6	25.5	166.8	9.6	3.3	0.4	254.8
1063–62	0.6	10.9	.....	37.7	25.5	166.7	9.7	3.2	0.5	254.8
1062–61	.....	11.9	.....	37.9	12.1	29.4	49.3	26.0	15.9	182.5
1061–60	.....	0.7	.....	11.0	2.7	.....	19.9	39.6	2.4	76.3
1060–59	.....	.....	.....	0.3	.....	.....	5.6	23.5	0.2	29.6
1059–58	.....	.....	.....	.....	.....	.....	2.0	2.7	.....	4.7
GARDEN ISLAND SHEET NO. 4										
1064–63	.....	0.2	.....	50.3	.....	188.8	5.1	0.7	0.1	245.2
1063–62	.....	0.1	.....	50.3	.....	188.8	5.2	0.7	0.2	245.3
1062–61	.....	.....	.....	108.7	.....	263.5	9.4	47.1	17.0	445.7
1061–60	.....	.....	.....	39.6	.....	.....	65.8	0.7	12.0	118.1
1060–59	.....	.....	.....	1.3	.....	.....	72.9	0.5	2.2	76.9
1059–58	.....	.....	.....	.....	.....	.....	69.4	0.5	.....	69.9
DRIFTWOOD TO STONEY SHEET NO. 5										
1064–63	.....	.....	.....	39.9	39.5	826.0	76.0	.....	7.6	989.0
1063–62	.....	.....	.....	39.8	39.5	826.0	76.1	.....	7.6	989.0
1062–61	.....	.....	.....	9.5	2.2	522.1	77.2	211.0	28.6	850.6
1061–60	.....	.....	.....	.....	.....	.....	0.3	372.5	12.3	385.1
1060–59	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1059–58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
STONEY CREEK SHEET NO. 6										
1064–63	0.2	.....	.....	81.7	51.4	529.9	2.5	0.8	7.1	673.6
1063–62	0.2	.....	.....	81.6	51.5	529.8	2.6	0.8	7.1	673.6
1062–61	0.2	.....	.....	118.7	45.0	335.9	178.1	31.1	16.8	725.8
1061–60	.....	.....	.....	52.8	16.2	5.0	320.8	368.2	3.6	766.6
1060–59	.....	.....	.....	3.2	.....	.....	211.9	376.3	.....	591.4
1059–58	.....	.....	.....	.....	.....	.....	18.5	277.3	1.2	297.0
REED RIVER SHEET NO. 7										
1064–63	0.6	0.2	.....	227.8	91.3	225.4	60.0	15.4	.....	620.7
1063–62	0.6	0.1	.....	227.9	91.2	225.4	60.0	15.4	.....	620.6
1062–61	0.1	0.7	.....	111.1	44.6	140.9	326.0	99.0	.....	722.4
1061–60	.....	.....	.....	28.0	3.0	0.6	501.2	1001.4	.....	1534.2
1060–59	.....	.....	.....	.....	.....	.....	79.0	61.6	.....	140.6
1059–58	.....	.....	.....	.....	.....	.....	27.1	31.0	.....	58.1

SURVEYED AREAS BETWEEN CONTOURS 1058 AND 1064—Continued

BY SHEETS—Continued

Contour	Cultivated Land	Grass Land	Grass Land with Scattered Poplar	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Total Area Acres
BUFFALO POINT SHEET NO. 8										
1064-63	.....	1.9	.....	195.7	63.3	489.5	19.5	749.6	10.1	1529.6
1063-62	.....	1.9	.....	195.6	63.4	489.4	19.6	749.6	10.1	1529.6
1062-61	.....	.....	.....	107.3	36.8	149.1	162.3	1621.5	3.7	2080.7
1061-60	.....	.....	.....	16.7	.....	11.0	238.4	2053.0	5.1	2324.2
1060-59	.....	.....	.....	.....	.....	.....	87.2	1140.8	5.6	1233.6
1059-58	.....	.....	.....	.....	.....	.....	9.1	1317.1	1.3	1327.5
ELM POINT SHEET NO. 9										
1064-63	2.5	4.8	.....	177.5	.....	98.5	.....	.....	.....	283.3
1063-62	2.6	4.7	.....	177.6	.....	98.4	.....	.....	.....	283.3
1062-61	0.9	75.1	.....	164.3	.....	146.3	60.1	.....	.....	446.7
1061-60	8.7	161.6	.....	29.6	.....	.....	243.7	1.2	6.5	451.3
1060-59	.....	.....	.....	0.5	.....	.....	260.2	179.1	.....	439.8
1059-58	.....	.....	.....	.....	.....	.....	9.7	610.9	.....	620.6
WARROAD SHEET NO. 10										
1064-63	87.6	36.2	.....	151.9	.....	.....	.....	1.4	.....	277.1
1063-62	87.7	36.1	.....	151.9	.....	.....	.....	1.5	.....	277.2
1062-61	37.9	86.0	.....	62.5	.....	.....	13.0	0.5	.....	199.9
1061-60	11.7	188.4	.....	14.9	.....	.....	30.2	.....	.....	245.2
1060-59	.....	.....	.....	0.9	.....	.....	50.9	256.8	.....	308.6
1059-58	.....	.....	.....	.....	.....	.....	34.7	177.7	.....	212.4
WILLOW CREEK SHEET No. 11										
1064-63	8.1	13.6	.....	126.4	.....	182.0	24.6	.....	.....	354.7
1063-62	8.0	13.6	.....	126.4	.....	182.0	24.7	.....	.....	354.7
1062-61	12.0	.....	.....	88.6	.....	213.9	140.3	50.5	.....	505.3
1061-60	.....	.....	.....	.....	.....	35.6	257.4	122.9	13.0	428.9
1060-59	.....	.....	.....	.....	.....	.....	207.2	424.3	1.0	632.5
1059-58	.....	.....	.....	.....	.....	.....	105.8	366.4	.....	472.2
ROCKY POINT SHEET NO. 12										
1064-63	.....	14.7	.....	374.2	.....	.....	23.8	.....	11.5	424.2
1063-62	.....	14.7	.....	374.2	.....	.....	23.7	.....	11.6	424.2
1062-61	.....	11.0	.....	227.2	.....	.....	163.0	.....	6.8	408.0
1061-60	.....	.....	.....	81.9	.....	.....	196.9	394.0	30.7	703.5
1060-59	.....	.....	.....	27.9	.....	.....	162.0	461.9	.....	651.8
1059-58	.....	.....	.....	.....	.....	.....	25.2	213.7	.....	238.9
LONG PT. TO ZIPPEL SHEET NO. 13										
1064-63	.....	0.8	.....	10.0	.....	25.3	.....	.....	.....	36.1
1063-62	.....	0.9	.....	10.0	.....	25.3	.....	.....	.....	36.2
1062-61	.....	.....	.....	.....	.....	7.5	.....	.....	.....	7.5
1061-60	.....	.....	.....	.....	.....	5.5	7.7	.....	1.3	14.5
1060-59	.....	.....	.....	.....	.....	.....	1.6	4.9	.....	6.5
1059-58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
ZIPPEL SHEET NO. 14										
1064-63	2.4	30.9	.....	118.6	.....	155.0	0.5	.....	3.3	310.7
1063-62	2.4	31.0	.....	118.5	.....	155.1	0.4	.....	3.3	310.7
1062-61	.....	32.0	.....	115.0	.....	139.5	12.4	.....	5.0	303.9
1061-60	.....	80.2	.....	14.7	.....	41.9	113.1	164.8	7.7	422.4
1060-59	.....	.....	.....	.....	.....	.....	53.5	345.0	.....	398.5
1059-58	.....	.....	.....	.....	.....	.....	.....	175.7	.....	175.7

SURVEYED AREAS BETWEEN CONTOURS 1058 AND 1064—Continued

BY SHEETS—Continued

Contour	Cultivated Land	Grass Land	Grass Land with Scattered Poplar	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Total Area Acres
FOUR MILE BAY SHEET NO. 15										
1064–63	.....	1.4	154.4	313.3	10.4	13.5	.....	9.3	7.2	509.5
1063–62	.....	1.5	154.4	313.2	10.5	13.4	.....	9.3	7.3	509.6
1062–61	0.6	71.5	151.3	130.7	3.2	1.1	28.3	.....	9.1	395.8
1061–60	.....	.....	96.1	38.1	.....	.....	34.3	82.9	10.3	261.7
1060–59	.....	.....	88.8	26.3	.....	.....	9.4	158.0	.....	282.5
1059–58	.....	.....	.....	.....	.....	.....	.....	77.8	.....	77.8
McGINNIS CREEK SHEET NO. 16										
1064–63	.....	73.3	40.5	118.8	41.6	86.1	65.6	6.8	8.8	441.5
1063–62	.....	73.3	40.6	118.7	41.7	86.1	65.5	6.8	8.8	441.5
1062–61	.....	80.1	26.0	46.7	0.4	3.1	170.3	66.4	17.9	410.9
1061–60	.....	61.9	16.2	3.0	.....	.....	169.1	149.3	14.4	413.9
1060–59	.....	31.2	4.1	.....	.....	.....	45.9	197.9	.....	279.1
1059–58	.....	.....	.....	.....	.....	.....	1.1	532.8	.....	533.9
WINDY POINT SHEET NO. 17										
1064–63	.....	18.6	.....	53.6	5.9	88.5	3.4	.....	5.4	175.4
1063–62	.....	18.6	.....	53.5	6.0	88.6	3.4	.....	5.4	175.5
1062–61	.....	29.1	.....	39.5	4.3	24.6	136.6	38.7	16.5	289.3
1061–60	.....	0.8	.....	0.8	.....	.....	80.9	60.4	41.8	184.7
1060–59	.....	.....	.....	.....	.....	.....	44.1	76.6	.....	120.7
1059–58	.....	.....	.....	.....	.....	.....	19.9	77.8	.....	97.7
LITTLE GRASSY SHEET NO. 18										
1064–63	17.4	7.7	.....	79.9	126.4	10.4	4.5	.....	.....	246.3
1063–62	17.3	7.7	.....	80.0	126.5	10.4	4.5	.....	.....	246.4
1062–61	5.3	20.1	.....	62.6	86.5	.....	136.8	0.7	3.3	315.3
1061–60	.....	9.5	.....	3.3	7.5	.....	92.6	0.4	3.2	116.5
1060–59	.....	.....	.....	.....	.....	.....	87.2	35.7	.....	122.9
1059–58	.....	.....	.....	.....	.....	.....	14.4	25.7	.....	40.1
BIG GRASSY SHEET NO. 19										
1064–63	8.3	11.7	.....	68.6	122.1	8.2	5.0	10.9	.....	234.8
1063–62	8.2	11.7	.....	68.7	122.0	8.3	5.0	10.8	.....	234.7
1062–61	7.2	13.5	.....	41.2	50.2	9.1	15.9	29.4	.....	166.5
1061–60	.....	3.3	.....	4.8	4.8	.....	35.1	14.0	.....	62.0
1060–59	.....	.....	.....	4.4	.....	.....	18.7	24.3	.....	47.4
1059–58	.....	.....	.....	.....	.....	.....	6.8	28.7	.....	35.5
BIGSBY ISLAND SHEET NO. 20										
1064–63	.....	5.3	.....	131.9	134.8	205.0	13.6	14.1	6.4	511.1
1063–62	.....	5.3	.....	131.9	134.8	205.0	13.6	14.1	6.4	511.1
1062–61	.....	.....	.....	70.0	39.9	88.2	238.9	327.1	16.4	780.5
1061–60	.....	.....	.....	1.4	.....	4.5	153.6	388.9	4.3	552.7
1060–59	.....	.....	.....	.....	.....	.....	107.8	198.7	0.4	306.9
1059–58	.....	.....	.....	.....	.....	.....	47.4	256.1	.....	303.5

SURVEYED AREAS BETWEEN CONTOURS 1058 AND 1064—Continued

BY SHEETS—Continued

Contour	Cultivated Land	Grass Land	Grass Land with Scattered Poplar	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Total Area Acres
BIG ISLAND (EAST) SHEET NO. 21										
1064-63				53.9	67.1	275.7	10.9	15.4	0.9	423.9
1063-62				53.9	67.2	275.6	10.9	15.5	0.9	424.0
1062-61				14.8	19.5	113.8	92.8	104.8		345.7
1061-60				0.4	1.5	1.5	53.2	81.4	2.5	140.5
1060-59							23.0	78.1		101.1
1059-58							14.8	69.8		84.6
BIG ISLAND (WEST) SHEET NO. 22										
1064-63		5.8		62.3	19.7	792.0	7.3	4.7	3.3	895.1
1063-62		5.7		62.4	19.6	792.1	7.3	4.7	3.3	895.1
1062-61		19.6		60.8	3.4	765.0	80.8	138.8	37.3	1105.7
1061-60		4.9		4.3	1.3	52.1	120.9	452.2	7.2	642.9
1060-59		0.1				0.5	25.1	266.6		292.3
1059-58							16.5	80.6		97.1
HAY RIVER SHEET NO. 23										
1064-63		6.8		113.8	15.6	134.8	30.8			301.8
1063-62		6.8		113.8	15.7	134.8	30.8			301.9
1062-61		25.7		49.9	7.5	66.9	59.9			209.9
1061-60				8.8	0.4	42.4	129.3	123.8		304.7
1060-59						3.2	40.8	179.5		223.5
1059-58							3.9	37.9		41.8
RICE BAY SHEET NO. 24										
1064-63		6.9		41.8	68.4	234.4	13.4	4.9		369.8
1063-62		6.9		41.7	68.5	234.4	13.3	4.9		369.7
1062-61		9.6		45.1	22.7	183.5	51.7	46.6		359.2
1061-60		2.1		11.6	6.1	38.6	100.9	299.3		458.6
1060-59				0.4		4.5	7.2	234.9		247.0
1059-58							1.3	15.9		17.2
FALCON RIVER SHEET NO. 25										
1064-63		8.1		40.1	58.0	160.1	52.9	372.5		691.7
1063-62		8.1		40.1	58.0	160.2	52.9	372.5		691.8
1062-61		34.7		31.6	29.7	128.1	128.5	242.3		594.9
1061-60		7.0		3.7	1.5	8.0	108.7	542.3		671.2
1060-59				0.4			19.0	146.0		165.4
1059-58							1.1	11.4		12.5

The areas here given between the 1064 and 1063 contours and those between the 1063 and the 1062 contours, it will be observed, are equal. This results from the fact that these areas were not separately determined, but were merely interpolated from the total measured area between the 1062 and the 1064 contours as previously given.

SUMMARY OF SURVEYED AREAS

BETWEEN CONTOURS 1058 AND 1064

CANADA

Sheet	Cultivated Land	Grass Land	Grass Land With Scattered Poplar	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Total Area Acres
1	1.8	81.2	.....	198.8	42.4	101.4	155.6	333.3	.....	914.5
2	.....	19.2	.....	212.5	91.0	263.8	142.7	481.2	.....	1210.4
3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	.....	.....	.....	.....	31.7	898.5	130.8	108.9	.....	1169.9
7	1.3	1.0	.....	594.8	230.1	592.3	1053.3	1223.8	.....	3696.6
8	.....	3.8	.....	515.3	163.5	1139.0	536.1	7631.6	35.9	10025.2
9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
16	.....	319.8	127.4	287.2	83.7	175.3	517.5	960.0	49.9	2520.8
17	.....	67.1	.....	147.4	16.2	201.7	288.3	253.5	69.1	1043.3
18	40.0	45.0	.....	225.8	346.9	20.8	340.0	62.5	6.5	1087.5
19	23.7	40.2	.....	187.7	299.1	25.6	86.5	118.1	.....	780.9
1-19	66.8	577.3	127.4	2369.5	1304.6	3418.4	3250.8	11172.9	161.4	22449.1
20	.....	10.6	.....	335.2	309.5	502.7	574.9	1199.0	33.9	2965.8
21	.....	.....	.....	123.0	155.3	666.6	205.6	365.0	4.3	1519.8
22	.....	36.1	.....	189.8	44.0	2401.7	257.9	947.6	51.1	3928.2
20-22	.....	46.7	.....	648.0	508.8	3571.0	1038.4	2511.6	89.3	8413.8
23	.....	39.3	.....	286.3	39.2	382.1	205.5	341.2	.....	1383.6
24	.....	25.5	.....	140.6	165.7	695.4	187.8	606.5	.....	1821.5
25	.....	57.9	.....	115.9	147.2	456.4	363.1	1687.0	.....	2827.5
23-25	.....	122.7	.....	542.8	352.1	1533.9	846.4	2634.7	.....	6032.6
1-19	66.8	577.3	127.4	2369.5	1304.6	3418.4	3250.8	11172.9	161.4	22449.1
20-22	.....	46.7	.....	648.0	508.8	3571.0	1038.4	2511.6	89.3	8413.8
23-25	.....	122.7	.....	542.8	352.1	1533.9	846.4	2634.7	.....	6032.6
1-25	66.8	746.7	127.4	3560.3	2165.5	8523.3	5135.6	16319.2	250.7	36895.5

UNITED STATES

1	.....	17.6	.....	143.1	12.2	.....	73.6	230.4	.....	476.9
2	0.1	49.9	.....	288.4	89.1	207.2	175.2	452.7	.....	1262.6
3	1.3	34.4	.....	124.5	65.8	362.9	96.1	98.3	19.4	802.7
4	.....	0.3	.....	250.2	.....	641.1	227.8	50.2	31.5	1201.1
5	.....	.....	.....	89.2	81.2	2174.1	239.6	583.5	56.1	3213.7
6	0.6	.....	.....	338.0	132.4	502.1	603.6	945.6	35.8	2558.1
7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	14.7	246.2	.....	549.5	.....	343.2	573.7	791.2	6.5	2525.0
10	224.9	346.7	.....	382.1	.....	.....	128.8	437.9	.....	1520.4
11	28.1	27.2	.....	341.4	.....	613.5	760.0	964.1	14.0	2748.3
12	.....	40.4	.....	1085.4	.....	.....	594.6	1069.6	60.6	2850.6
13	.....	1.7	.....	20.0	.....	63.6	9.3	4.9	1.3	100.8
14	4.8	174.1	.....	366.8	.....	491.5	179.9	685.5	19.3	1921.9
15	0.6	74.4	645.0	821.6	24.1	28.0	72.0	337.3	33.9	2036.9
16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
17	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
20-22	See Canada Sheets									
23-25	See Canada Sheets									
1-25	275.1	1012.9	645.0	4800.2	404.8	5427.2	3724.2	6651.2	278.4	23219.0

SUMMARY OF SURVEYED AREAS—Continued

BETWEEN CONTOURS 1058 AND 1064—Continued

CANADA AND UNITED STATES

Sheet	Cultivated Land	Grass Land	Grass Land with Scattered Poplar	Deciduous Trees	Mixed Deciduous and Coniferous	Coniferous Swamp	Willows and Brush	Open Marsh or Bog	Sand	Total Area Acres
1	1.8	98.8	.....	341.9	54.6	101.4	229.2	563.7	.....	1391.4
2	0.1	69.1	.....	500.9	180.1	471.0	317.9	933.9	.....	2473.0
3	1.3	34.4	.....	124.5	65.8	362.9	96.1	98.3	19.4	802.7
4	.....	0.3	.....	250.2	.....	641.1	227.8	50.2	31.5	1201.1
5	.....	.....	.....	89.2	81.2	2174.1	229.6	583.5	56.1	3213.7
6	0.6	.....	.....	338.0	164.1	1400.6	734.4	1054.5	35.8	3728.0
7	1.3	1.0	.....	594.8	230.1	592.3	1053.3	1223.8	.....	3696.6
8	.....	3.8	.....	515.3	163.5	1139.0	536.1	7631.6	35.9	10025.2
9	14.7	246.2	.....	549.5	.....	343.2	573.7	791.2	6.5	2525.0
10	224.9	346.7	.....	382.1	.....	.....	128.8	437.9	.....	1520.4
11	28.1	27.2	.....	341.4	.....	613.5	760.0	964.1	14.0	2748.3
12	.....	40.4	.....	1085.4	.....	.....	594.6	1069.6	60.6	2850.6
13	.....	1.7	.....	20.0	.....	63.6	9.3	4.9	1.3	100.8
14	4.8	174.1	.....	366.8	.....	491.5	179.9	685.5	19.3	1921.9
15	0.6	74.4	645.0	821.6	24.1	28.0	72.0	337.3	33.9	2036.9
16	.....	319.8	127.4	287.2	83.7	175.3	517.5	960.0	49.9	2520.8
17	.....	67.1	.....	147.4	16.2	201.7	288.3	253.5	69.1	1043.3
18	40.0	45.0	.....	225.8	346.9	20.8	340.0	62.5	6.5	1087.5
19	23.7	40.2	.....	187.7	299.1	25.6	86.5	118.1	.....	780.9
1-19	341.9	1590.2	772.4	7169.7	1709.4	8845.6	6975.0	17824.1	439.8	45668.1
20	.....	10.6	.....	335.2	309.5	502.7	574.9	1199.0	33.9	2965.8
21	.....	.....	.....	123.0	155.3	666.6	205.6	365.0	4.3	1519.8
22	.....	36.1	.....	189.8	44.0	2401.7	257.9	947.6	51.1	3928.2
20-22	.....	46.7	.....	648.0	508.8	3571.0	1038.4	2511.6	89.3	8413.8
23	.....	39.3	.....	298.3	39.2	382.1	295.5	341.2	.....	1383.6
24	.....	25.5	.....	140.6	165.7	695.4	187.8	606.5	.....	1821.5
25	.....	57.9	.....	115.9	147.2	456.4	363.1	1687.0	.....	2827.5
23-25	.....	122.7	.....	542.8	352.1	1533.9	846.4	2634.7	.....	6032.6
1-19	341.9	1590.2	772.4	7169.7	1709.4	8845.6	6975.0	17824.1	439.8	45668.1
20-22	.....	46.7	.....	648.0	508.8	3571.0	1038.4	2511.6	89.3	8413.8
23-25	.....	122.7	.....	542.8	352.1	1533.9	846.4	2634.7	.....	6032.6
1-25 (Canada)	66.8	746.7	127.4	3560.3	2165.5	8523.3	5135.6	16319.2	250.7	36895.5
1-25 (United States)	275.1	1012.9	645.0	4800.2	404.8	5427.2	3724.2	6651.2	278.4	23219.0
1-25 (Total)	341.9	1759.6	772.4	8360.5	2570.3	13950.5	8859.8	22970.4	529.1	60114.5

SUMMARY OF MAPS

MAPS COMPRISING ATLAS

Index Map of Lake of the Woods Sheets—Southerly Shore, showing Sheets 1 to 25.

Scale: $\frac{1}{253,440}$=4 miles to 1 inch.

Map showing Triangulation Control of Lake of the Woods and Shoal Lake Surveys.

Scale: $\frac{1}{253,440}$=4 miles to 1 inch.

Lake of the Woods Sheets—Southerly Shore, Series of twenty-five sheets.

Scale: $\frac{1}{24,000}$=2000 feet to 1 inch.

Sheets Nos. 1–19 showing surveys from the Northwest Angle Inlet to Big Grassy River.

No. 1. Northwest Angle Sheet.
No. 2. Buckete Island Sheet.
No. 3. Oak Island Sheet.
No. 4. Garden Island Sheet.
No. 5. Driftwood to Stoney Sheet.
No. 6. Stoney Creek Sheet.
No. 7. Reed River Sheet.
No. 8. Buffalo Point Sheet.
No. 9. Elm Point Sheet.
No. 10. Warroad Sheet.
No. 11. Willow Creek Sheet.
No. 12. Rocky Point Sheet.
No. 13. Long Point to Zippel Sheet.
No. 14. Zippel Sheet.
No. 15. Four Mile Bay Sheet.
No. 16. McGinnis Creek Sheet.
No. 17. Windy Point Sheet.
No. 18. Little Grassy River Sheet.
No. 19. Big Grassy River Sheet.

Sheets Nos. 20–22 showing surveys of portions of Bigsby and Big Islands.

No. 20. Bigsby Island Sheet.
No. 21. Big Island Sheet (East).
No. 22. Big Island Sheet (West).

Sheets Nos. 23–25 showing areas surveyed around Shoal Lake.

No. 23. Hay River Sheet.
No. 24. Rice Bay Sheet.
No. 25. Falcon River Sheet.

Rainy Lake Sheets, showing surveys of Portions of Shore of Rainy Lake in the vicinity of Rat Root River and Stanjikoming Bay. Series of four sheets.

Scale: $\frac{1}{24,000}$=2000 feet to 1 inch.

Sheets Nos. 1–4.

No. 1. Rat Root River Sheet.
No. 2. Black Bay Sheet.
No. 3. Cranberry Bay Sheet.
No. 4. Stanjikoming Bay Sheet.

Key Map of the Lake of the Woods Reconnaissance Sheets—Northerly Shore.

Scale: $\frac{1}{323,000}$=5.1 miles to 1 inch.

Lake of the Woods Reconnaissance Sheets—Northerly Shore. Sketches of Portions of Northerly Shore from Shoal Lake to Big Grassy River. Series of three sheets.

Scale: $\frac{1}{24,000}$=2000 feet to 1 inch.

Sheets Nos. 1–3.

No. 1. Sketches 1 to 75.
No. 2. Sketches 76 to 133.
No. 3. Sketches 134 to 190.

Kettle Falls Sheets, showing surveys of Lakes above Kettle Falls. Series of four sheets.

Scale: $\frac{1}{48,000}$=4000 feet to 1 inch.

Sheets Nos. 1–4.

No. 1. Kabetogama Lake Sheet.
No. 2. Namakan Lake Sheet.
No. 3. Sand Point Lake Sheet.
No. 4. Little Vermilion Lake Sheet.

Map showing surveys of Connecting Channels of Lakes above Kettle Falls.

Plan showing Cross Sections of Overflow Channels between Kabetogama, Namakan and Rainy Lakes, also certain Sections in Channels at Kettle Falls.

Scale: Vertical, 40 feet to 1 inch. Horizontal, 160 feet to 1 inch.

Watershed Map of the Lake of the Woods, compiled mainly from maps of the Department of the Interior, Canada, and Map of the State of Minnesota, prepared (1912) by the United States Geological Survey.

Scale: $\frac{1}{500,000}$=7.89 miles to 1 inch.

MINOR MAPS APPEARING IN VOLUME OF PLATES

	Plate
Watershed of the Lake of the Woods showing Mean Annual Isohyetals	1
Watershed of the Lake of the Woods showing Mean Annual Isotherms	2
Watershed of the Lake of the Woods showing Mean Summer Isotherms	3
Watershed of the Lake of the Woods showing Mean Winter Isotherms	4
Watershed of the Lake of the Woods showing Forest Reserves	15
Watershed of the Lake of the Woods showing Location of Logging Dams	126
Watershed of the Lake of the Woods showing Forest Cover	*
Watershed of the Lake of the Woods showing Character of Soil	*
Key Plan of Outlets, Lake of the Woods	19
Sketch Map of Winnipeg River from Keewatin to White Dog Rapids	20
Map of Eastern Outlet of the Lake of the Woods	23
Map of Western Outlet of the Lake of the Woods	25
Key Map of Rainy Lake showing Location of Low Areas	*
Sketch Map showing Location of Hydrographic Stations on Rainy River and Rainy Lake	*
Map of Pithers Rapids, Rainy River	77
Map of Koochiching Falls in State of Nature	76
Map of Manitou Rapids, Rainy River	144
Map of Long Sault Rapids, Rainy River	143

* This Map appears in the Volume of Text.

CLASSIFICATION OF SURVEYED AREAS

The notes and descriptions pertaining to culture classifications as set forth below have been prepared particularly with reference to the areas adjacent to the larger lakes embraced within the surveys of the International Joint Commission only, and not to the main portions of the watershed.

In order to preserve the identity of the various measurements as recorded by the planimeters, it has been necessary to tabulate the readings as actually given by the instruments. It must not therefore be inferred that the areas have been determined with the precision that might be indicated by the decimals of acres given.

CULTIVATED LAND

Under the heading "Cultivated Land" are listed all lands that were under cultivation at the time of the surveys, or that gave evidence of ever having been worked with the object of producing, in the past, any field crops.

There were certain areas which appeared to have been broken by the plough at some prior time, and which with comparatively little trouble might again be brought under cultivation. Instances were observed where such land had not been tilled during recent years and where a small growth of brush, perhaps 3 or 4 feet in height, had sprung up. However, even all such areas have been included under the classification "Cultivated Land." Illustrations of brush growth appearing upon abandoned arable land are found in the Northwest and Northeast quarters of Section 33, Township 163 North, Range 36 West, Minnesota (Sheet No. 10). The larger part, over 75 per cent, of all lands in this classification is included within the territory shown on Sheets Nos. 9, 10, 18 and 19.

The total area under this classification below elevation 1064 is 341.9 acres, of which 275.1 acres are in the United States, and 66.8 acres in Canada. The total area below elevation 1062 is 84.6 acres, of which 72.0 acres are in the United States and 12.6 acres in Canada. Representative illustrations of cultivated land are found on Sheets No. 10 and No. 18, and shown on Plates E and I.

GRASS LAND

Under the classification "Grass Land" is placed any land cleared of both timber and medium or heavy brush which affords no evidence of ever having been ploughed, and also those small open areas, found along streams, on which true wild hay may be cut.

The classification, "Grass Land" however, does not include land which, while cleared, was found to lie at an elevation low enough to permit the water to overflow it for periods sufficiently long to render the grass growth practically worthless for feeding purposes.

"Grass Land" for the most part, lies adjacent to the shores of creeks or streams.

The principal growth on areas classified as "Grass Land" consists of red top or blue joint. At the higher elevations there may be small areas of clover, but as compared with other grasses, the amount of clover is insignificant.

The grasses growing upon what is here classified as "Grass Land" must not be confused with the growths found upon land which we have classified as "Open Marsh or Bog." The growth upon the latter consists principally of wire grass and other marsh grasses. They are largely of aquatic character and have practically no value for feeding purposes.

The character of the grasses found upon any given area bordering the shore of the lake depends largely upon the prevailing lake stages.

There are certain areas within the town of Warroad where there is good cleared land that might be regarded as arable land, inasmuch as it has undoubtedly been ploughed at some time and might, without much trouble, be again brought under cultivation. Since, however, it is situated within the limits of Warroad, it does not appear desirable to classify it as ordinary cultivated land. On account of its location, it would more fittingly be regarded as town real estate. On the maps showing the surveys of Lake of the Woods these areas in Warroad are represented by grass symbols. These particular areas, therefore, if separately considered, have a different status from "Grass Land" in general. The acreage, however, of such grass land in the town of Warroad is quite small, being under 70 acres. It all lies above elevation 1061; 80 per cent of it is above elevation 1062 and 75 per cent above elevation 1064.

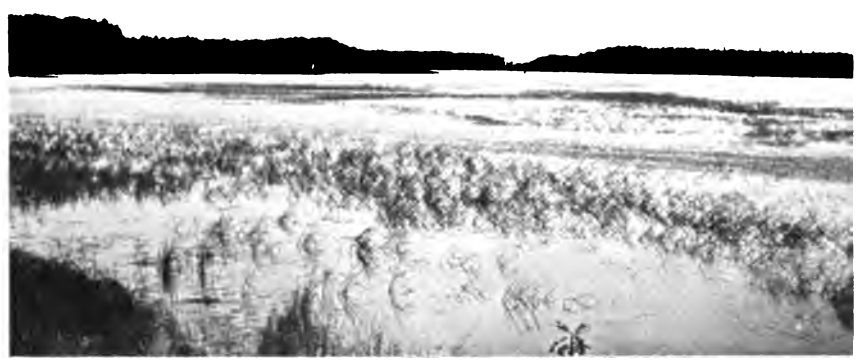
In those places where "Grass Land" and "Open Marsh or Bog" adjoin with no readily distinguishable line of demarcation, the 1061 contour, for the purpose of measurement and classification, has conventionally been adopted as the dividing line between the two growths. There are instances, as, for example, on Falcon and Hay Rivers, streams tributary to Shoal Lake, where, along the upper reaches, "Open Marsh or Bog" occurs even above the 1064 contour. Obviously in such instances it is not practicable to regard any contour as a conventional dividing line.

The major portion —over 55 per cent—of all lands classified as "Grass Land" is included within the territory shown on Sheets Nos. 9, 10, 14 and 16.

The total area under this classification below elevation 1064 is 1759.6 acres, of which 746.7 acres are in Canada, and 1012.9 acres in the United States. The total area below elevation 1062 is 1156.8 acres, of which 407.5 acres are in Canada, and 749.3 acres are in the United States. A small area of "Grass Land" is shown on Plate I along the creek flowing into Rice Bay.

A South Shore Wheat Field—August 18, 1913

Rice Bay on Shoal Lake—Open Marsh Along Creek and Wild Rice in Lake



Wild Rice in Snake Lake Near Falcon River

GRASS LAND WITH SCATTERED POPLAR

The area under this classification occurs only on Sheets No. 15 and No. 16 and amounts, in all, to 772.4 acres. The area is ordinary grass land so covered with small scattered poplar that it is impossible to designate it either as purely "Grass Land" or as "Deciduous Trees."

DECIDUOUS TREES

Under the classification "Deciduous Trees" are placed poplar, birch, elm, ash and oak. This, approximately, is the order of the combined extent and value of this group, of which poplar is the most prevalent. On the drier arable land, poplar, birch and elm are found, and ash on the swampy ground. Scrub oak, usually subsisting on rocky soil, is the only variety of this tree found within the areas covered by the surveys. Poplar was found ranging in size from small second growth to 12 inches, with an average of about 6 inches; birch were found as large as 15 inches and elm up to 20 inches in diameter. The ash trees are usually small, the larger size being from 6 to 8 inches in diameter.

It may be perceived from the maps that parcels of land falling within this classification prevail to a large extent over the territory included within the surveys. Representative examples of deciduous trees are found on Sheets No. 12 and No. 20, and shown in the upper picture of Plate K.

The total area under this classification below elevation 1064 is 8360.5 acres; of which 4800.2 acres are in the United States, and 3560.3 acres in Canada. The total area below elevation 1062 is 2435.4 acres, of which 1545.3 acres are in the United States and 890.1 acres in Canada.

MIXED DECIDUOUS AND CONIFEROUS

Under the classification "Mixed" trees are placed the deciduous trees just referred to when found associated and intermingled with the coniferous, namely, spruce, balsam, cedar or pine and occasionally tamarack. Areas classified under "Mixed Deciduous and Coniferous," so far as tree growth is concerned, are, generally, productive of trees of fairly large size.

Over 55 per cent of all lands classified as "Mixed Deciduous and Coniferous" is included within the territory shown on Sheets Nos. 6, 7, 18, 19, 20, and 24. Representative examples may be found on Sheet No. 18 and No. 19.

The total area under this classification below elevation 1064 is 2570.3 acres, of which 404.8 acres are in the United States, and 2165.5 acres in Canada. The total area below elevation 1062 is 510.4 acres, of which 115.3 acres are in the United States and 395.1 acres in Canada.

CONIFEROUS SWAMP

A large amount of the land included in the International Joint Commission surveys is classified under "Coniferous Swamp." Such land has upon it growths of the smaller tamarack, spruce, balsam or cedar. Generally speaking the growth on these swamps, except in instances where poles, fence posts, and some railroad ties may profitably be marketed, is not commercially valuable. The tamarack and spruce, except in isolated instances, are quite small, averaging about 6 or 7 inches in diameter.

The general swamp floor consists of the usual well known hummocky mossy growth.

Over 55 per cent of all lands classified as "Coniferous Swamp" is included within the territory shown on Sheets Nos. 5, 6, 7, 8, 21, and 22 and representative examples may be found on Sheets No. 5 and No. 22. A typical coniferous swamp is shown on Plate J.

The total area under this classification below elevation 1064 is 13,955.7 acres, of which 8528.5 acres are in Canada and 5427.2 acres in the United States. The total area below elevation 1062 is 3747.2 acres, of which 2131.8 acres are in Canada and 1615.4 acres in the United States.

WILLOWS AND BRUSH

The willow growths met with are chiefly of two kinds; namely, the large "Diamond willow," and the small "Red willow."

Diamond willows grow in bunches or clumps, attaining a height as great as 12 or more feet. Each bunch is usually made up of from, say, 6 to 12 separate stocks, each about 2½ inches in diameter. The willows are not found growing on bog which is actually floating. They require soil that has some substance, although it requires to be swampy or at least well saturated with moisture. This requirement of soil explains why these willows are usually found along the outer edge of the tree line, and often extend out as far as the commencement of the floating bog. Willows are sometimes found dead but still standing in several feet of water well out towards the lake. This is probably accounted for by the fact that the roots of the willows had penetrated into soil which was firm enough to prevent the tree floating to the surface under the influences exerted by increased stage of water. Where willows have been thus encroached upon by deep water for any considerable time, as for example, for a season or two, they have died. Dead willows are found not only at the edge of the deeper water out towards the lake, but also where they had been growing on gradually sloping bottom, along what might be termed the "line of the willows proper."

Alder brush, which has been included under this classification, possesses much the same characteristics as the diamond willows;

TYPICAL SHORELINE AT EDGE OF CONIFEROUS SWAMP OR MUSKEG NEAR DRIFTWOOD POINT

DRIFTWOOD AROUND SETTLER'S CABIN NEAR MOUTH OF RAINY RIVER LAKE OF THE WOODS

TYPICAL SETTLER'S CABIN NEAR WILLOW CREEK—LAKE OF THE WOODS

PLATE K

HEAVY STAND OF DECIDUOUS TREES AND SURVEY CAMP—BUFFALO POINT, LAKE OF THE WOODS

HEAVY STAND OF NORWAY PINE ON ROCKY SHORE OF LAKE KABETOGAMA

TYPICAL ROCKY SHORE ON NORTHERLY PORTION OF RAINY LAKE

PLATE L

CUT OVER, BURNT OVER AND WIND-BLOWN SHORE—BIRCH LAKE, MINN.

PINE GROWING IN SCANT SOIL—BLOWN OVER WHERE EXPOSED

the principal difference perhaps being that the former is found on somewhat drier ground, and its growth is more dense. Alder brush is found growing along the low ground bordering small creeks or draws, and is frequently found interspersed with both the diamond and the red willow.

Red willows are smaller than diamond willows. The height to which they generally attain is not more than about 5 feet. They do not grow in water nor in clumps like the diamond willow. Probably the greater portion of the red willow growth embraced within the surveys is on land partaking more of the nature of the cranberry muskeg. A good illustration of red willow growth is found on Bigsby Island about 6400 feet due east of the lighthouse.

Over 55 per cent of all lands classified as "Willows and Brush" is included within the territory shown on Sheets Nos. 5, 6, 7, 8, 9, 11, 12, 16 and 20. Representative examples may be found on Sheet No. 7 and No. 20. Willow brush is also shown in picture No. 5 on Plate G and in the lower picture on Plate M.

The total area under this classification below elevation 1064 is 8996.4 acres, of which 5177.2 acres are in Canada and 3819.2 acres in United States. The total area below elevation 1062 is 8071.8 acres, of which 4556.2 acres are in Canada and 3515.6 acres in the United States.

OPEN MARSH OR BOG

The classification "Open Marsh or Bog" includes principally those areas, free of trees or brush, consisting of marshy or to a certain extent submerged lands lying along the lake shore between the outside line of trees or willows and the shoreline—conventional or otherwise—as shown on our maps.

Areas classified under "Open Marsh or Bog" manifest different physical conditions at their outer, or lakeward edge, from what they do on their landward, or inner edge. On the inner and higher portion of the "Open Marsh or Bog," as found during the survey, between about elevation 1060 and the tree line, we have, generally speaking, the "Open Marsh," the sod of which is anchored by roots to a comparatively firm subsoil. Between the 1060 contour and the lake, however, the land gradually becomes softer and more spongy, so that between the 1059 contour and the lake shore the greater portion usually becomes what may be styled "Floating Bog," the character of which is described below. Above the 1060 contour the ground, with the exception of a few minor areas, is firm. Below the 1059 contour it is safe to say that almost all the area is of the spongy or of the floating type. In the expression "Open Marsh or Bog" the word "Bog" really represents, as far as our classification is concerned, both spongy and floating bog.

The following brief statement will serve to illustrate the character of some of this "Open Marsh or Bog," and how it behaves under wave action.

When the water surface of a lake is raised some of the sod of the original ground surface becomes loosened, breaks away from the firmer soil beneath, and floats to the surface of the water. During the first few years this floating mass is probably not very tough or strong; but as time goes on, and as the grass growth becomes heavier and its roots stronger and more firmly interwoven, the sod as a mass also becomes tougher and firmer. It may be 6 inches to a foot or more in thickness and varies greatly in toughness. At places a heavy man may walk over it, while in other parts a man of even light weight cannot walk without breaking through.

The bog is frequently underlaid by a soft black ooze or muck, to a depth, in places, of as much as 6 feet. This muck may have a consistency varying all the way from muddy water to that of ordinary mud. In most places there is a firm subsoil at a depth of from 2 to 5 feet, but occasionally no marked subsoil is encountered even at a depth of 6 feet or more below the surface. It has been noticed, however, that the ooze or muck usually increases in firmness with depth, and at a depth of 6 feet a rod could not be pushed down further into the muck without exerting considerable pressure.

Peat bogs, similar to those found around the Lake of the Woods, are of common occurrence in other parts of northern Minnesota. At a place near Bemidji, Minnesota, for example, one of our engineers, in making borings for a bridge foundation some years previous, found about 16 feet of black muck overlying a stratum of sand.

In places this ooze or muck works out into the lake, and is again washed in by wave action and covers up, or washes out growth, such as marsh grass, or wire grass, which might otherwise get a foothold. Areas illustrative of the open marsh or bog which abound along the southerly shore may be found, for example, along the shore two miles either east or west from Mr. Landby's farm, which is located about five miles southeast of Warroad in Section 1, Township 162 N., R. 36 W. A typical portion of this bog is shown on Plate H.

Processes of Nature which have resulted in the formation of portions of the shores of the Lake of the Woods are, of course, similar to those which are found operating on many other bodies of water. Around the borders of many of the rock-bound lakes, such as are found in the rocky formations of northern Minnesota and northwestern Ontario, there are to be found numbers of large and small isolated areas of open marsh or floating bog. The process by which some portions of such shores have been formed may be suggestively mentioned:

By erosion of material adjacent to the inner portion of bays and coves there becomes deposited over such areas sufficient soil to

PLATE M

HIGH SANDY SHORE—BUFFALO POINT

OPEN MARSH OR BOG—NEAR REED RIVER

MARSH WITH SCATTERED BRUSH—NEAR STONEY POINT

enable a growth, chiefly of aquatic vegetation, to commence. After this growth has become established, and as it approaches deeper water, such plants as the sphagnum moss continue to grow above and die from beneath with only partial decay. Such material as does decay settles in the water and eventually reposes upon the bottom of the lake, or extends around portions of the lake as a floating fringe. When this raft of aquatic vegetation becomes sufficiently dense and firm, the sedges, small willows and aquatic shrubs obtain a hold. At later periods on some of these areas the tamarack appears. It not infrequently happens that large areas of floating heathy bog break away and drift about the lake impelled by the wind. Numbers of instances are on record where large fields of marsh or swamp grass have broken loose and drifted so as to become a menace to bridges, dams, nets, etc., or to cause trouble in other ways. Typical illustrations of floating bog are shown on Plate F.

There are many places along the southerly shore where the "Open Marsh or Bog" area between the 1059 and 1061 contours is more of the open marsh and less of the floating bog type. The growth over these open marsh areas is usually sedge rather than wire grass because the latter grows to better advantage where the bog is floating.

Although there are some places where bulrush or cat-tail growths occur on floating bog, yet as a rule these growths are found springing from comparatively firm ground which may be covered by water up to a depth of two or more feet. These growths constitute a kind of transition link between water reeds proper, which may grow in 6 feet or more of water, and those plants which grow only on the drier ground.

The aquatic growths as they die may be found passing through various stages of decomposition towards the formation of peaty bogs. In the more northerly climates the breakdown and decomposition of vegetable fibre is usually a comparatively slow process. Numerous samples of such areas examined around the shores show that the Lake of the Woods in this respect is no exception. The growth on the "Floating Bog" comprises "wire" grass,* and other marsh grasses, bulrushes, cat-tails or cranberry bushes.

A good illustration of purely floating bog is found on Sheet 8, where there is an area of some 1800 acres lying between contours 1059 and 1061. The greater part of the "Open Marsh or Bog" in this vicinity, Sheet 8, is of the floating type, extending inland even to the 1064 contour. Conditions here would be changed but little

*Wire grass and other marsh grasses, in certain localities, are harvested by some manufacturing companies for use in the manufacture of mats, carpets, etc. Representative instances of where this growth occurs are found on Sheet 8, Sections 1, 12, 13, 14, 23 and 24 of Township 1, Range 16 E., Manitoba, and Sections 7, 17, 18, 19, 20 and 29 of Township 1, Range 17 E., Manitoba. Extensive areas are also found on Sheets 9, 10, 11, 16 and 25.

even if the lake stage were dropped a few feet lower. The growth over this area is practically all wire grass.

In order to present some comparison of the relative amounts of floating bog and open marsh, it may be stated that for Sheets Nos. 9 to 15 out of a total "Open Marsh or Bog" area of 7425.5 acres about 30 per cent of the area is open marsh and about 70 per cent floating bog.

There are large areas, as for example, on Sheet No. 8 in the vicinity of Buffalo Bay, where up to about contour 1061 it is probable that this part of "Open Marsh or Bog" area was never anything different in character from what it is today, and could in no sense whatever be regarded as land which might be brought under cultivation even if the level of the lake were lowered a few feet. On the other hand, however, if one considers portions of the "Open Marsh or Bog" to the south of Warroad, some of the shore land in this locality, other conditions being favorable, has been demonstrated by the growing of crops to be capable of cultivation.

In addition to the areas above described, there are certain low areas, with distinctive characteristics, situated well back from the lake and known as "cranberry muskeg." The strata under such areas, although of much the same nature, are usually considerably firmer than those which exist beneath the floating bog; that is to say, there is manifested the firmer substratum of grass root, and then a shallow stratum of muck, which shades gradually into sand, or sometimes clay. Over these cranberry muskegs there is no pronounced grass growth. The surface consists of mossy hummocks presenting a rough and uneven appearance. The moss may be, say, 6 to 12 inches in thickness, but just below it, the surface roots and runners are so interwoven as to offer, between the hummocks, fairly good support.

Springing from this moss is a growth of small and scattered brush, usually from 2 feet to 4 feet or more in height. Sometimes there is a light growth of red willows, and frequently, also, areas of small scattered tamarack or spruce; but the chief characteristic growth is the low cranberry bush from which this class of muskeg derives its name.

Typical cranberry muskeg may be found on Sheet 22, Section 3, Township 2, Range 21 E., and on Sheet 21 in the southern part of Sections 11 and 12, Township 2, Range 21 E. It has all been classified as "Open Marsh or Bog." The total area of cranberry muskeg is probably under 1000 acres.

Portions of the area classified as "Open Marsh or Bog," very probably owe some of their present characteristics to the fact that the level of the Lake of the Woods has, during recent years, been at higher stages for longer periods than was formerly the case.

WAVES BREAKING UPON PINE ISLAND

THIS SETTLER'S GARDEN PLOT OFFERED SCANT RESISTANCE TO THE BREAKERS DURING STORM IN 1914

REMAINS OF A PORTION OF OAK POINT—LAKE OF THE WOODS—1914

The classification "Open Marsh or Bog" cannot as a whole be regarded as consisting of areas suitable for agricultural purposes. However, it may be stated that in the course of our surveys some areas at about contour 1061, were located where the conditions of drainage, mode of cultivation, etc., were favorable for the production of certain crops, and where crops had even been grown; but these areas are exceptional and cannot in any sense be regarded as representative of the character of the great proportion of the areas comprised under the classification of "Open Marsh or Bog." Which of the various areas comprised within the classification "Open Marsh or Bog" possess agricultural properties would have to be specially ascertained.

Over 50 per cent of all lands classified as "Open Marsh or Bog" is included within the territory shown on Sheets Nos. 6, 7, 8, 9, 11 and 25. For representative examples see Sheets No. 8 and No. 11.

The total area under this classification of "Open Marsh or Bog," below elevation 1064, is 28,941.9 acres; of which 10,413.1 acres are in the United States, and 18,528.8 acres in Canada. The total area below elevation 1062 is 26,501.7 acres; of which 10,380.7 acres are in the United States and 16,121.0 acres in Canada.

SAND

On most of the sheets are areas which have been designated as "Sand," and almost invariably they occur either on the bars thrown up by the water along the shore, or else on low lying sand islands. It everywhere consists of the ordinary yellow beach sand and the only vegetation which springs from it is made up of a few coarse weeds, sparse and worthless grass, or small scattering brush.

Over 50 per cent of all areas classified as "Sand" is included within the territory shown on Sheets Nos. 5, 12, 15, 16, 17 and 22. Representative examples may be found on Sheets No. 12 and No. 17.

The total area under this classification below elevation 1064 is 529.1 acres, of which 278.4 acres are in the United States, and 250.7 acres in Canada. The total area below elevation 1062 is 384.5 acres, of which 203.6 acres are in the United States and 180.9 acres in Canada.

WATER

The classification "Water" applies to all those instances where the 1054 contour lies outside the shoreline appearing on the maps of the International Joint Commission surveys, and includes all the area lying between the shoreline and the line marked by that contour. The classification therefore may include areas in inland lakes and ponds. Extensive water areas are found on every sheet.

The position of the shoreline as located by the United States General Land Office Surveys between 1895 and 1904 is found to lie,

in most places, well outside the shoreline as determined by the International Joint Commission surveys in 1913 and 1914. This may be explained partly by the fact that erosion has occurred along the lake shore since the time of the Land Survey. A considerable area, consequently, which would formerly have come under the classification of land has been transformed into a water area.

REEDS

The expression "reeds" represents various aquatic growths such as those rushes and grasses which are found growing in a considerable depth of water along the shores of lakes similar to the Lake of the Woods.

In general, reeds mark the outer limit of plant growths which rise above the surface of the water. On the maps of our surveys it will be seen that in all cases the reeds lie outside the shoreline even where this line may be regarded as somewhat conventionalized. In those places where a conventional shoreline has been shown on the map as, for example, in portions of the Northwest Angle Inlet, the reed growth in the lake merges gradually into marsh grass as the water becomes shallower and there is no sharp line of demarcation between the two growths.

The area covered by reeds has been regarded in the classification of areas as though it were "water" lying outside the shoreline. The various reedy growths included under the term "reeds" as shown on the maps consist chiefly of the following:

A. Reeds with a single, long, hollow stem, often so widely scattered that a boat may pass freely through them.

B. Reeds with a single hollow stem and a pair of opposite long drooping leaves, frequently growing quite dense, and presenting an appearance resembling a very large variety of grass.

C. Wild Rice, (See Plate I) usually found in small lakes or in the arms of larger lakes. Where the water is of a fairly uniform depth of about from 4 to 7 feet it occurs in quite extensive areas. Dr. Geo. M. Dawson, Geologist and Botanist to the British North America Boundary Commission, commenting on physical conditions on the Lake of the Woods as found by him in the years 1873 and 1874, respecting Wild or Indian Rice, says:

"The wild, or Indian rice, does not occur abundantly in the southern part of the lake, so far as I have seen, but must grow luxuriantly in some parts of the northern division, and especially in Lac Plat,* where the Indians collect large quantities of the seed in autumn, for winter use. The plant appears to thrive best where growing up through several feet of water in sheltered lagoons and inlets, and certain areas formerly noted for its production have of late years, from the higher level of the water, become unproductive * * *."

* Now known as Shoal Lake.

D. Bulrushes, usually found in comparatively shallow water, and which frequently merge into areas covered with the various marsh grasses.

Reeds of Classes B and C constitute the chief reed growth in rivers and streams and are mainly found growing between the banks and the edge of the deeper channel. A good example of the occurrence of reeds of Class B may be found at the mouth of the Rainy River.

In sheltered places on the lakes and streams there was frequently found a growth which is a water weed rather than a reed. It is an annual growth, found usually in less than ten feet of water, which rises fernlike from the bottom until it forms a mat floating at the surface of the water. It is found over considerable areas, but it is not included in the reed areas on the maps.

ROCK

The area classified as "Rock" is of no importance, the total for the 25 sheets amounting to only 36.5 acres. All of this lies below the 1064 contour, and more than 50 per cent of it is found on Sheet No. 24.

The classification is made up chiefly of narrow, barren stretches along high shorelines, where the surveys were made more for the sake of securing continuity of shoreline than for any importance attaching to the areas involved. The area comprises also a number of small low lying rock islands having the characteristics of reefs such as are found on Sheets Nos. 1 to 4 and Nos. 16 to 25.

METEOROLOGICAL DATA PERTAINING TO THE LAKE OF THE WOODS WATERSHED

INTRODUCTORY COMMENTS

In the interpretation of hydrological data, and in the study of hydraulic problems on all watersheds, particularly on those for which stream flow records are meager, or extend over a comparatively short period of years, meteorological data are of fundamental importance. The runoff from every watershed is the direct result of precipitation. The distribution of that runoff, throughout the year, depends primarily upon the prevailing temperatures and their relation to the character and distribution of the rainfall.

The runoff from most portions of the Lake of the Woods watershed, as manifested by the flow of streams, was not measured until recent years. On the other hand, meteorological phenomena have been observed at a number of stations on the watershed for a considerable period of time.

Of the rain and snow which falls upon any given drainage basin, a portion is again evaporated from the land and water surfaces; another portion is taken up by the roots of plants, serving as a vehicle for the transportation of required mineral substances to the leaves, and is again transpired into the air as vapor; most of the remaining portion of the precipitation runs off over the surface into the streams, or sinks into the ground to reappear in the lakes and rivers as seepage flow. Knowing the rainfall, the temperature, the principal physical characteristics of a watershed, and the more important of the laws that govern evaporation and transpiration, it is possible to compute, with reasonable accuracy, the portion of the rainfall which is lost through the processes of evaporation and transpiration, and thus to secure a reasonably accurate value for the residual rainfall which is left over, and which appears in the streams as "runoff." Such values may then be used for the purpose of supplementing and verifying other hydrographic data.

Inasmuch as temperature and precipitation records are basic data in the present investigation, these records for all meteorological stations on or near the Lake of the Woods watershed, at which observations have been taken since 1885, have been collected, and are arranged by years and months in Tables 1 and 2.

Meteorological data for stations in the United States, previous to 1891, were collected by the Signal Service Bureau of the War Department. During this period there were three classes of stations;

first, regular stations; second, stations at military post hospitals; and third, volunteer stations, corresponding to the present co-operative Weather Bureau stations.

During the early years, Duluth and St. Vincent ranked as stations of the first class. Pembina, or Fort Pembina, as it was known at that time, was a military post hospital.

Since 1891, Moorhead and Duluth have been maintained as regular Weather Bureau stations, where complete records are kept of all ordinary meteorological phenomena. All other stations in or near the United States portion of the Lake of the Woods watershed for which data are here given, have been maintained as co-operative stations, the observer receiving no compensation besides certain publications of the Weather Bureau. He records only precipitation, temperature, and the general state of the weather.

The snowfall at most co-operative-observer stations is reduced to its equivalent in rain by dividing by ten. At regular Weather Bureau stations the snow is usually melted, so that more accurate values of winter precipitation are, on the whole, obtained at these latter stations.

Meteorological data for stations in Canada are collected by the Meteorological Service of the Department of Marine and Fisheries, Canada, with its head office at Toronto, Ontario.

The classification of stations which has obtained in this Office is as follows:

Chief Stations, where all ordinary observations are taken day and night at equal intervals of time not exceeding four hours.

Telegraph Reporting Stations, where all ordinary observations are taken at 8 a. m., 2 p. m., and 8 p. m., 75th Meridian time.

Ordinary Stations of the First Class, where all the ordinary observations are taken three times daily at certain local times.

Ordinary Stations of the Second Class, where observations of temperature, rainfall and snowfall, direction and velocity of the wind, and the state of the weather are taken two or three times daily at regular hours.

Ordinary Stations of the Third Class, where records are kept of the fall of the rain and snow, and general state of the weather.

Of the Canadian stations for which data are here presented, Winnipeg ranks as a Chief Station, Port Arthur as a Telegraph Reporting Station, and the others rank as stations of the First Class, except Barclay, which was a station of the Third Class until 1888.

At most of the stations of the Second Class the observers render their services without compensation. Since May, 1913, meteorological observations have also been made by the Manitoba Hydrographic Survey at Keewatin, Ontario.

All records of snowfall taken at stations of the Canadian Meteorological Service which have been used in this report, were reduced to their equivalent in rain by dividing by ten.

On the basis of certain physical characteristics, the Lake of the Woods watershed may be conveniently divided into three sections, viz., the Upper Rainy Watershed—being the portion above International Falls and Fort Frances; the Lower Rainy Watershed—being the portion below International Falls and above the mouth of Rainy River; and the watershed of the Lake of the Woods Proper—being the portion which, excepting the Rainy River, drains directly into the Lake of the Woods above its outlets at Keewatin and Kenora.

In general, the Upper Rainy watershed and the watershed of the Lake of the Woods Proper, possess very similar characteristics,—the underlying Laurentian rock formation outcropping frequently, the soil cover being scant, lakes and ponds numerous, and the timber growth, on the whole, rather sparse. The Lower Rainy watershed is more heavily forested and generally rather flat and swampy, much of the land requiring drainage before it will be suitable for agricultural purposes.

The area of the Upper Rainy watershed is 14,500 square miles; that of the Lower Rainy watershed is 6,350 square miles; and that of the watershed of the Lake of the Woods Proper is 5,900 square miles, making a total area above the outlets of the Lake at Keewatin and Kenora of 26,750 square miles. The mean annual rainfall on these watershed subdivisions, based on observations extending from 1885 to 1913, is 24.99, 24.47, and 22.16 inches respectively; and the mean annual temperature is 34.9, 36.5, and 34.8 degrees respectively.

It may here be remarked, that the period dating from 1885 was used, mainly, because meteorological data previous to that date are very meager, and because some of the testimony taken during the Preliminary Hearings referred to rainfall and lake stages as far back as the years 1885 and 1886.

In view of the fact that differences of elevation in the drainage area tributary to the Lake of the Woods are comparatively small, the influence exerted on the precipitation by these differences is believed to be relatively unimportant, except perhaps, in the extreme south-eastern portion, where a change of about 1,000 feet in elevation occurs in a distance of about 20 miles. It is also probable that the large expanse of open water of Lake Superior will exert some influence on the character of the early winter precipitation at such stations as Duluth, Two Harbors, and Port Arthur.

PRECIPITATION

Relative to the length of time required to secure a true mean rainfall record, Sir Alexander R. Binnie* has stated that the mean derived from 35 years of good records will probably differ by 2 per

* Proceedings Institution of Civil Engineers, Vol. CIX (1892) pp. 89-172.

cent from the true mean for a long period of years; the mean of 20 years' records will probably vary 3.25 per cent from the true mean; the 15 year mean 4.75 per cent; the 10 year mean 8.25 per cent; and the 5 year mean will probably differ by 15 per cent from the true mean.

Mr. Alfred J. Henry in his "Rainfall of the United States",* writes that the average variation of a 25 year mean is about 5 per cent, and of a 40 year mean about 3 per cent from the true mean. In the same report Mr. Henry also discusses the effect of the location and elevation of rain gauges upon the catch of the gauge.

In this connection it is interesting to note, for example, that the mean precipitation at Duluth, Minnesota, from 1871 to 1913, is 29.42 inches, while the mean from 1885 to 1913 is 27.21 inches,—a variation of the 29 year mean from the 43 year mean of minus 2.21 inches, or minus 7.5 per cent. The mean precipitation at Winnipeg, Manitoba, from 1873 to 1913 is 21.41 inches, while the mean from 1885 to 1913 is 20.17 inches,—a variation of the 29 year mean from the 41 year mean of minus 1.24 inches, or minus 5.9 per cent. The mean precipitation at Pembina, North Dakota, from 1872 to 1913 is 19.36 inches, while the mean from 1885 to 1913 is 18.87 inches,—a variation of the 29 year mean from the 40 year mean of minus .49 inches, or minus 2.5 per cent.

Reliable precipitation records for Winnipeg are available from 1873 to date; for Port Arthur from 1878 to date; for Winnibigoshish and Pokegama Falls from 1888 to date; for Savanne from 1886 to 1905; and for Hallock from 1900 to date. Records are available for Mount Iron from 1894 to 1910, but seem to give a considerably larger precipitation than the neighboring stations, and so are not given full weight. For instance, the record of 1896 gives the annual precipitation for Mount Iron as 39.47, while Tower nearby has 29.50 inches, and the maximum recorded for any other station was 32.96 inches at Winnibigoshish. During the years 1895 and 1905, the Mount Iron records of 36.10 inches and 42.83 inches respectively, are very much higher than those for any other neighboring station. During 1903 and 1904, the excess of recorded precipitation at Mount Iron over that at neighboring stations is perhaps due to the recording of an excessive amount of snowfall as rainfall, on the assumption that 10 inches of snow equals 1 inch of rain. For these reasons the Mount Iron records are not given the weight which the length of the period of observation would otherwise warrant.

Records of precipitation at International Falls are available for scattered periods from 1892 to date, with only two complete yearly records up to 1909, since which time continuous records are available

* Report of the Chief of the Weather Bureau, 1896-7, Page 317.

at this station. For the years 1911, 1912, and 1913, a comparison of the precipitation records for International Falls and Little Fork gives an average of 25.46 and 20.34 inches respectively. This indicates either local storms, or discrepancies in measurement of precipitation. On account of this fact, and the short and irregular record, the International Falls station is not given full weight.

Regarding the Canadian stations it should be noted that Winnipeg is a "Chief Station" and Port Arthur is a "Telegraph Station," as previously stated, and records from these should therefore be reliable. The location of Savanne makes it a station of considerable value in estimating the precipitation on the Upper Rainy watershed. The Savanne records are considered reliable by the Meteorological Service.*

It is very probable that some error is involved in the measurement of winter precipitation when it occurs as snow. Where the snow is not melted, a ratio of 1 inch of water to 10 inches of snow is almost universally used in both the United States and Canada. Actual measurements, however, show that this ratio varies from 1 inch of water for 6 or 7 inches of heavy snow, to 1 inch of water for 15 or 20 and occasionally even 30 inches of light snow. As the depth of snowfall is necessarily measured at a place reasonably convenient for the observer, it may be influenced by drifting. The same weight cannot, in general, be given to precipitation records from voluntary observer stations where the winter snowfall is reduced to its equivalent rainfall by dividing by 10, as can be given to the records from stations where the depth of snowfall is carefully measured and the snow melted. When discrepancies are apparent in winter values of precipitation, these may often be traced to discrepancies in the constant used for reducing snowfall to rainfall.

Plate 1 shows lines of equal rainfall, or isohyetals, for the Lake of the Woods watershed. In constructing these curves, the period 1885 to 1913 was taken as the basis, and conventionalized lines of equal mean annual precipitation drawn in such manner as was warranted by the data at hand. Most of these data are summarized in Tables 1 and 2. More complete records may show local variations which are not brought out by the incomplete data at hand, but the curves are believed to be substantially correct, subject to changes, of course, when longer records are available at a greater number of stations. A number of stations in Minnesota and North Dakota, the full records for which are not published in this report, were used to help fix the lines of equal precipitation at the southern and western boundaries of the watershed. Where stations with from eight to twenty-five years' records were used in locating lines of equal pre-

* Annual Report, 1890, page xxiii.

cipitation, these records were reduced to an equivalent long term record by comparison with a neighboring long term station for a similar period.

In estimating monthly precipitation for the three sections into which the total watershed of the Lake of the Woods has been divided for convenience in studying runoff, Plate 1 was used, to some extent, as a guide. Where records were available for a number of stations in any one section, as in recent years on the Lower Rainy watershed, the problem of estimating monthly precipitation was comparatively simple. In these instances, an average of the records for any given month has been taken after each record was weighted according to its reliability, and its geographic position on the watershed. For the earlier years, however, during which the records were few and incomplete, and for the Upper Rainy watershed as well as for the watershed of the Lake of the Woods Proper, the estimate of monthly precipitation is based largely on the records of precipitation at outlying stations, in so far as these indicate storm paths, or show the general trend of precipitation for each month.

As previously mentioned, more complete records, especially for the central and northern portions of the watershed, would have been of invaluable assistance in making these estimates, and would unquestionably have increased their accuracy.

MEANS AND EXTREMES OF MONTHLY PRECIPITATION ON WATERSHED SUBDIVISIONS

The curves of Plates 5, 7, and 9 are presented to show the variations in average monthly precipitation, which have occurred over the three watershed subdivisions, between 1885 and 1913. Five curves are shown for each subdivision of the Lake of the Woods watershed, viz., the mean precipitation for each month, the monthly precipitation of the wettest year and of the driest year, the minimum and the maximum precipitation recorded in each month for the entire period of 29 years.

Evidently a maximum precipitation of about 6.5 inches per month may be expected in June, July, or August, over the entire area of any one of the watershed subdivisions. In any one month of the year the precipitation on any one of the watershed subdivisions may not exceed 1.25 inches. In a very wet year a total of about 11 inches of rain may be expected in two months over the entire watershed tributary to the Lake of the Woods, whereas in a very dry year this may not exceed 4 inches.

Plate 11 shows the average annual precipitation that occurred on the three main watershed subdivisions during the years 1885 to 1913, inclusive, together with the mean for the entire period. A summary of precipitation data is also given in Tables 3 to 5.

The curves of Plate 11 show a prevalence of dry years near the beginning and near the end of the 29 year period, indicating cycles of dry and wet years recurring in about 25 years. Similar indications of cycles of from 25 to 35 years have frequently been noted in other observations of natural phenomena. The recurrence of periods of dry and wet years, as indicated by the data here presented, must be taken into account when considering the significance of stages which have prevailed on the Lake of the Woods and other lakes on the watershed, during the past years.

TEMPERATURE

Plates 2, 3, and 4 show mean annual isotherms, mean summer isotherms, and mean winter isotherms, for the Lake of the Woods watershed. The summer isotherms represent the mean temperature for the months of June, July, and August, and the winter isotherms represent the mean temperature for the months of December, January, and February. Longer records may necessitate some shifting of these curves.

Temperature data extending without interruption through the entire 29 year period, from 1885 to 1913, were available for comparatively few stations. Instead of platting the observed mean annual temperatures, and precipitations, for periods of varying length, an effort has been made to reduce the mean derived from records covering a varying number of years, to an equivalent mean for the 29 year period between 1885 and 1913. It has been assumed that the monthly mean temperatures for the 29 year period at any two stations would bear, approximately, the same relation to each other as the monthly mean temperatures, at those stations, for any small number of years.

Typical curves showing, graphically, the relation between the mean monthly temperatures at a number of selected stations are shown on Plates 12 and 13. The years selected for comparison are, in each case, determined by the period for which records are available.

Data for the graphs on Plate 12 extend over the entire 29 year period from 1885 to 1913, for all stations except Pembina, where records for the years 1896, 1897, and part of 1898 are missing.

Data for the graphs on Plate 13 include the 21 year period between 1885 and 1906, with the exception of the year 1899.

The records at Winnibigoshish and Pokegama Falls, and also those at Pembina and St. Vincent, have been averaged, and each average value has then been treated as the record of a single station, because of the proximity of these stations, and furthermore, because there is an occasional month's record missing at either one or the other station. In this way, the effect of small errors of observation

and of local disturbances has also been reduced. The mean record, however, was virtually given double the weight of the record from any single station.

The variation in mean annual temperature of stations on the Lake of the Woods watershed is much less than the variation in annual rainfall. For example, the mean temperature for the last 10 years at Duluth differs from the mean for the last 29 years by minus 2.1 per cent. For Winnipeg the difference between the mean temperature for the last 10 years and that for the last 26 years is plus 2.0 per cent. In view of this small difference between the 10 year mean and the 26 to 29 year means, it may be stated that the estimated mean temperature for the 29 year period from 1885 to 1913, derived from records extending over 10 or more years, is substantially correct.

The greatest departure of any single annual mean from the mean temperature for the entire period at the above mentioned stations, is only about 15 per cent.

In estimating monthly temperatures for the three watershed subdivisions during the later years when records are fairly complete, a weighted mean was determined from available data, as in the case of monthly precipitation. When the records were incomplete at any given station, as was the usual case during the earlier years, a temperature was estimated for that station on the basis of the curves of Plates 12 and 13, and similar unpublished curves, showing the mean relationship prevailing between the monthly temperatures at the given station and those at some other station at which records were available for the given month.

The isotherm charts of Plates 2, 3, and 4, were, also, of assistance in this work.

As in estimating precipitation, more complete records, especially in the central and northern portions of the watershed, would have been of great assistance in estimating monthly temperatures, although the increase in accuracy would not have been material, in view of the relatively gradual and regular variations which occur in temperature.

MEANS AND EXTREMES OF MONTHLY TEMPERATURES ON WATERSHED SUBDIVISIONS

The curves of Plates 6, 8, and 10 show the mean, the minimum, and the maximum monthly temperatures, and the average temperatures which prevailed during the twelve months of the coldest and of the warmest years on the various watershed subdivisions.

A variation of from 20 to 25 degrees in monthly temperature during winter, spring, and fall, will be noted. Such changes in temperature, as this, result in variations of at least 100 per cent in the evaporation loss from the watershed, and hence have a tremendous

effect on the available stream flow. During the summer months the extreme variation in monthly temperature is about half as great as the variation during the winter, spring, and fall months. Changes in temperature affect not only the evaporation from a watershed, but also the transpiration, i. e., the water used by growing plants. Consequently, while the variation in summer temperatures is not as great as the variation in winter temperatures, the combined evaporation and transpiration losses may show as much, or more variation in summer than the evaporation loss resulting from the larger temperature variations in winter, spring, and fall.

A summary of monthly and mean annual temperatures on the watershed subdivisions is given in Tables 3, 4, and 5.

EVAPORATION

In view of the large water areas existent on the watershed of the Lake of the Woods, evaporation losses, as well as their distribution throughout the year, are important among the various factors which govern the available runoff from this watershed.

The following discussion of the subject of evaporation from water, snow and ice surfaces, is taken from Mr. Meyer's paper entitled "Computing Runoff from Rainfall and other Physical Data," published in the March, 1915, Proceedings of the American Society of Civil Engineers.*

"Although the laws of evaporation, as stated by Professor Thomas Tate, are thirteen in number, the writer has found that in computing stream flow only three factors tending to modify evaporation need usually to be considered. These are, in the order of their importance: temperature, humidity, and wind. The last two are relatively unimportant within the ordinary range of variation, but some allowance from watershed to watershed, and month to month, must be made for wide differences.

"The writer has accepted the principle, first enunciated by Dalton, that the rate of evaporation from a water surface, other conditions remaining constant, varies almost, if not quite, as the difference between the maximum vapor pressure corresponding to the temperature of the water, and the pressure of vapor present in the atmosphere.

"Inasmuch as maximum vapor pressure is a function of the temperature—doubling for every increase of approximately 18° Fahr.—the actual pressure of vapor present in the atmosphere also becomes a function of the temperature when the relative humidity remains constant. In other words, the rate of evaporation is approximately doubled for every 18° rise in temperature for constant humidity and wind velocity. Within the range of annual variation in temperature

* The quotation from Mr. Meyer's paper here given comprises pages 558 to 574.

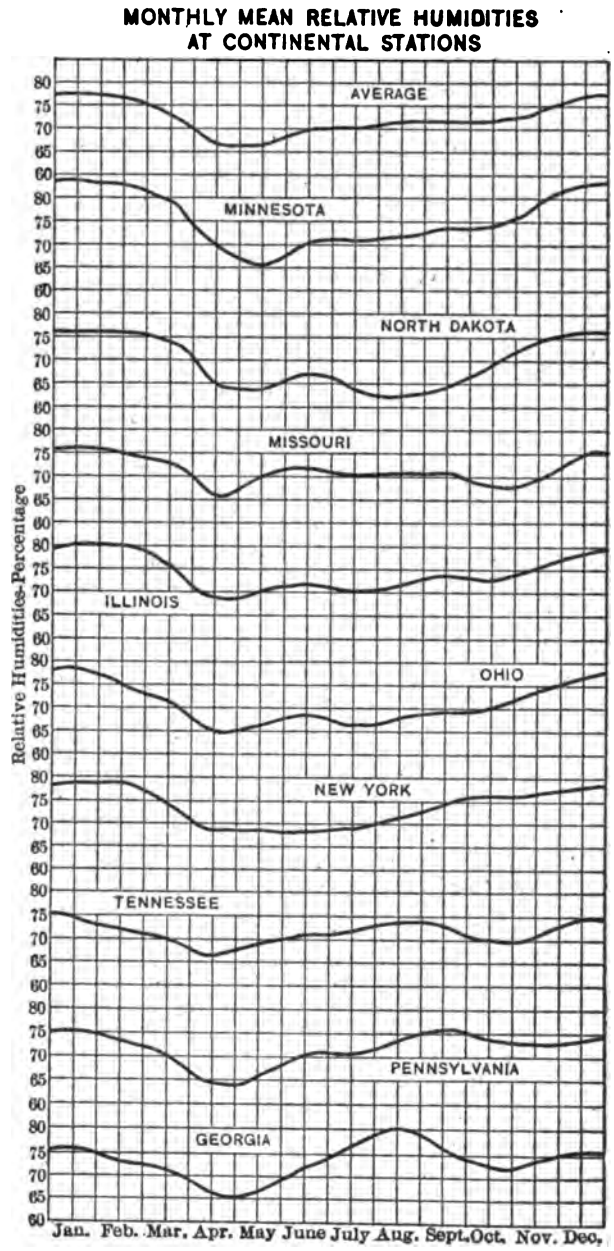


FIG. 4.

98896—17——6

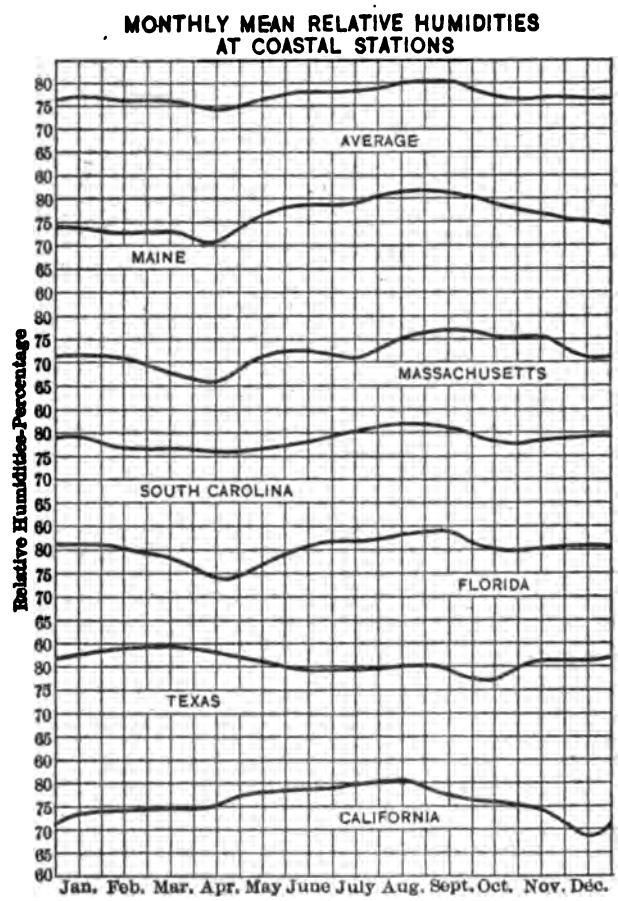

MONTHLY MEAN RELATIVE HUMIDITIES
AT COASTAL STATIONS
Relative Humidities-Percentage
AVERAGE
MAINE
MASSACHUSETTS
SOUTH CAROLINA
FLORIDA
TEXAS
CALIFORNIA
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.

FIG. 5.

prevailing throughout the Northwest, the rate of evaporation will vary about 700 to 1200% due to temperature changes alone.

"Figs. 4 and 5 show graphically the monthly mean relative humidity at a number of widely distributed points throughout the United States, outside of the arid region of the West. It will be noted that the monthly values in any State vary by only about 15 to 20% during the open season. Other conditions remaining constant, evaporation would vary only about 30 to 50%.

"The effect of wind on evaporation has been given various weights by different writers on the subject. Wielenmann, Stelling, and Tate, hold that evaporation varies approximately directly as the wind velocity. DeHeen, Shierbeck, and Svenson, hold that it varies as the square root of the wind velocity. Russell found a wind factor which, for wind velocities up to 15 or 20 miles per hour, could be represented approximately by the equation $1 + \frac{w}{4}$. FitzGerald found a wind factor represented by the equation $1 + \frac{w}{2}$. Bigelow, in his first evaporation formula, published in 1908, used a wind factor of about $1 + \frac{w}{35}$. Three years later he changed this to about $1 + \frac{w}{11}$. The writer believes that these formulas, giving the effect of wind on evaporation, refer to wind velocity at the elevation of the water surface in the basin from which evaporation was measured. The wind velocity, as observed by the Weather Bureau, is, in general, about three times the wind velocity at the surface of the earth.

"In view of the discordant conclusions reached by the above mentioned experimenters with respect to the effect of wind on evaporation, the writer believes that no particular refinement is justified in selecting a wind factor. After checking observed and computed evaporation at a number of stations, using various wind factors, the writer has tentatively adopted $1 + \frac{w}{10}$ as representing the effect of wind on the evaporation of water from surfaces at the level of the ground, where w represents wind velocity as observed by the Weather Bureau about 30 ft. above the general level of the surrounding country.

"Using the writer's wind factor of $1 + \frac{w}{10}$, the annual variation in evaporation due to changes in monthly mean wind velocity amounts to only about 20 to 30 per cent. The monthly mean wind velocity at a number of stations in the eastern two-thirds of the United States is shown graphically in Fig. 6.

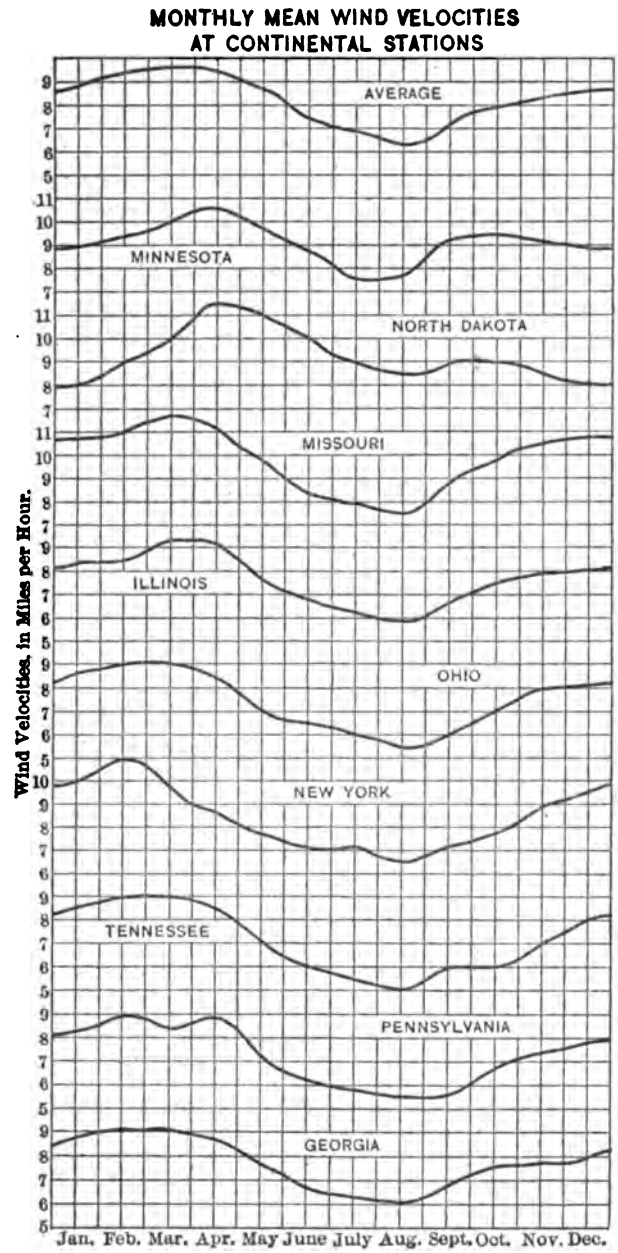

MONTHLY MEAN WIND VELOCITIES
AT CONTINENTAL STATIONS
AVERAGE
MINNESOTA
NORTH DAKOTA
MISSOURI
ILLINOIS
OHIO
NEW YORK
TENNESSEE
PENNSYLVANIA
GEORGIA
Wind Velocities, in Miles per Hour.
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.

FIG. 6.

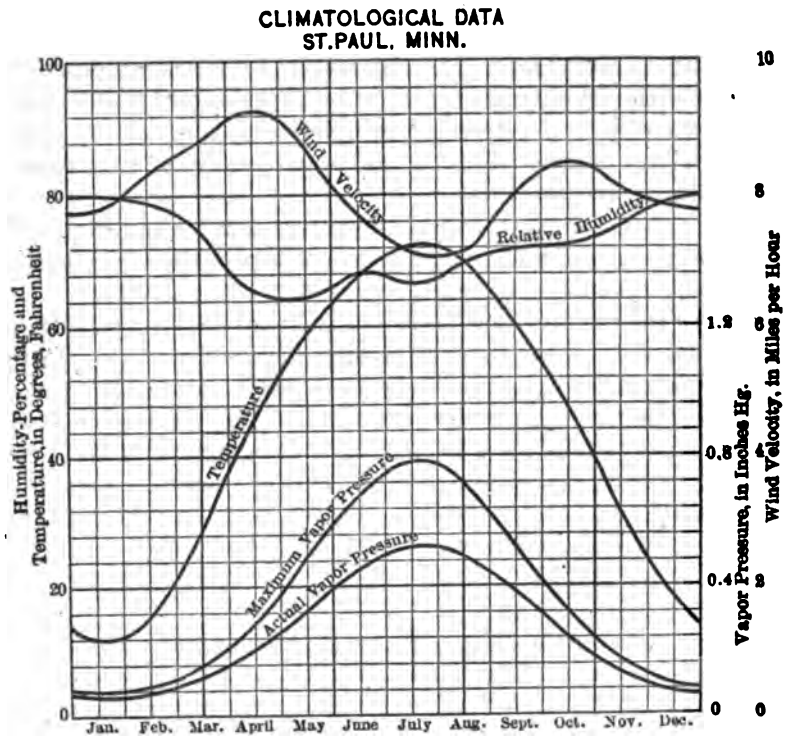

CLIMATOLOGICAL DATA
ST. PAUL, MINN.
Humidity-Percentage and Temperature, in Degrees, Fahrenheit
Vapor Pressure, in Inches Hg.
Wind Velocity, in Miles per Hour
Wind Velocity
Relative Humidity
Temperature
Maximum Vapor Pressure
Actual Vapor Pressure
100
80
60
40
20
0
10
8
6
4
2
0
1.2
0.8
0.4
0
Jan. Feb. Mar. April May June July Aug. Sept. Oct. Nov. Dec.

FIG. 7.

"Fig. 7 shows the monthly mean relative humidity, wind velocity, air temperature, maximum vapor pressure, and the actual pressure of vapor present in the atmosphere at St. Paul, Minn. Neither relative humidity nor wind velocity, it will be observed, varies between wide limits. The vapor pressures and their differences, that is, the factor which virtually determines evaporation, all show variations of several hundred per cent.

"Fig. 8 shows the evaporation from shallow water for different temperatures and seasons of the year, under conditions prevailing throughout the Northwest. A fundamental error has sometimes been made in plotting evaporation records, owing to failure to differentiate between the observed values at the different seasons of the year, all months being thrown together indiscriminately and evaporation plotted against temperature.

"By plotting separate values of evaporation for equal spring and fall temperatures, humidity and wind velocity for the given locality are properly taken into account.

"Both the Grand River Lock and the University, North Dakota, evaporation stations are on small shallow bodies of water. The mean relative humidity at the North Dakota station is slightly less, and the wind velocity slightly greater than at the Wisconsin station. Monthly observations have been grouped together and the average taken. Observations of temperature and evaporation extend over the years, 1905 to 1913, inclusive. These values have been averaged by months, and the results are shown in Table 1.

TABLE 1

OBSERVATIONS OF TEMPERATURE AND EVAPORATION

Month	At University, North Dakota		At Grand River Lock, Wisconsin	
	Air temperature, in degrees Fahrenheit	Evaporation, in inches per month	Air temperature, in degrees Fahrenheit	Evaporation, in inches per month
April	45	3.37	45	2.83
May	52	4.08	54	4.35
June	65	5.00	64	5.52
July	67	5.81	68	5.74
August	66	4.60	65	4.46
September	57	3.57	59	3.45
October	45	2.02	48	2.22
November	*34	*0.52	*41	*1.09

* Observations extended over portions of the month only.

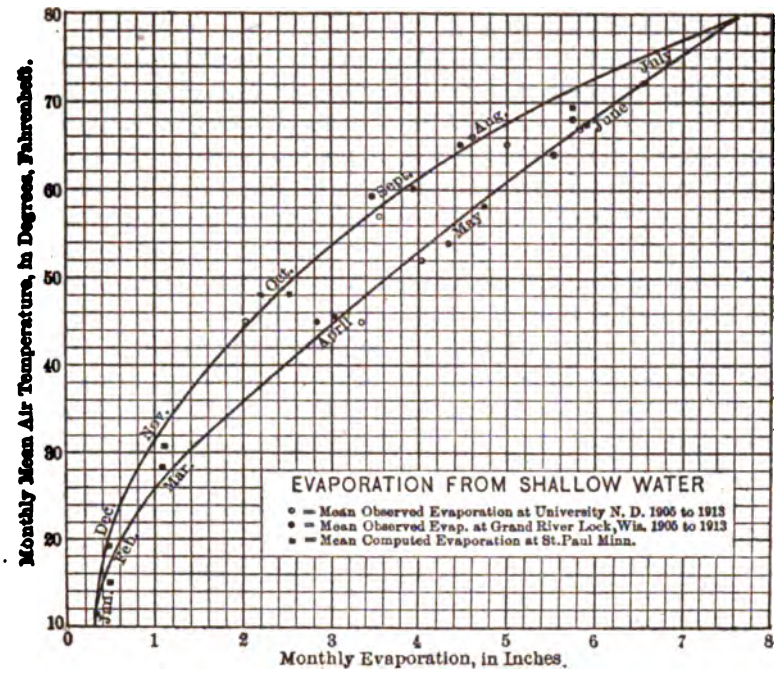

EVAPORATION FROM SHALLOW WATER
• = Mean Observed Evaporation at University N. D. 1905 to 1913
• = Mean Observed Evap. at Grand River Lock, Wis. 1905 to 1913
• = Mean Computed Evaporation at St. Paul Minn.
Monthly Mean Air Temperature, in Degrees, Fahrenheit.
Monthly Evaporation, in Inches.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

FIG. 8.

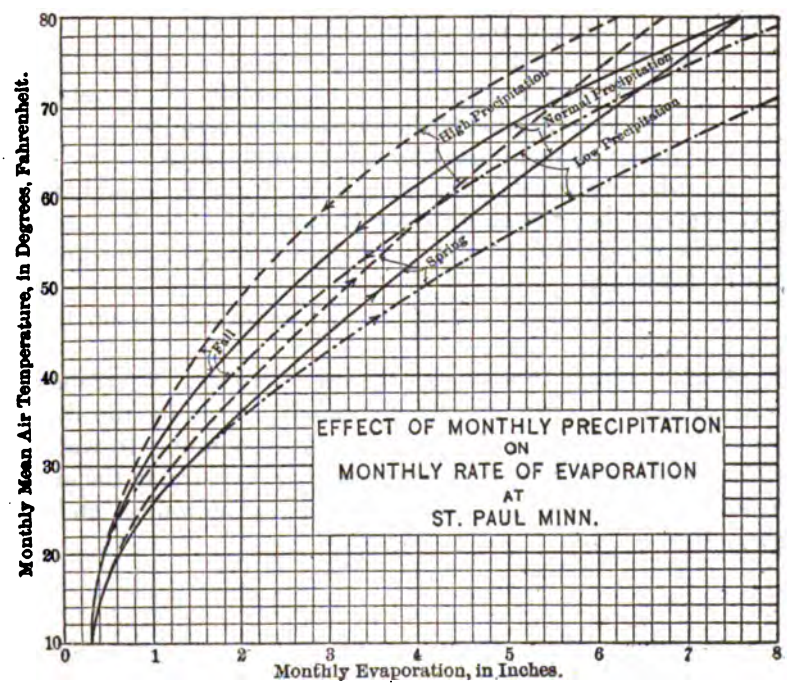

EFFECT OF MONTHLY PRECIPITATION
ON
MONTHLY RATE OF EVAPORATION
AT
ST. PAUL MINN.
High Precipitation
Normal Precipitation
Low Precipitation
Fall
Spring
Monthly Mean Air Temperature, in Degrees, Fahrenheit.
Monthly Evaporation, in Inches.

FIG. 9

"During several successive months of either high or low precipitation a marked change in relative humidity is noticeable. Fig. 9, showing the effect of high and low rates of monthly precipitation on evaporation, is computed from meteorological data for St. Paul, Minn. The effect shown must be considered more or less approxim ate because based on relatively few data, yet indicative of the variation in monthly evaporation resulting from large variations in monthly precipitation, and hence basic to the later discussion pertaining to the proportion of precipitation lost by evaporation from land areas, at any given temperature, for various rates of rainfall. Both higher and lower than normal rates of precipitation, in inches per month, seem to affect the rate of evaporation less in early spring than in fall. This might be expected because the moisture available for evaporation in the spring is less dependent on rainfall than it is in the fall, hence the relative humidity would not be affected by changes in precipitation as readily in spring as in fall.

"The evaporation at St. Paul, Minn., was computed by the following formula:

$$E = 15\,(V - v)\left(1 + \frac{w}{10}\right)$$

in which E = Evaporation, in inches per month;

V = Maximum vapor pressure, in inches of mercury, at monthly mean air temperature;

v = Actual vapor pressure, at monthly mean air temperature and relative humidity;

w = Wind velocity, in miles per hour, as measured by the Weather Bureau, approximately 30 ft. above the general level of the surrounding country.

"The data and computations are given in Table 2.

"In order to show a further comparison between actual and computed evaporation, the records for Mount Hope, N. Y., have been used. The observed data and the computations for this station are given in Table 3.

"The data cover a varying period beginning between 1891 and 1896, and ending in 1912.

"For January, February, March, October, November, and December, the evaporation was computed by taking the difference between the maximum vapor pressure corresponding to water temperature, and subtracting an assumed vapor pressure, in the air above the water, based on the observed relative humidity and water temperature.

"From April to September, inclusive, the evaporation was computed by taking the difference between the maximum vapor pressure, corresponding to water temperature, and the actual vapor pressure in the air as determined from the air temperature and the observed relative humidity.

TABLE 2

COMPUTED EVAPORATION AT ST. PAUL, MINN.

Month	Temperature*	Maximum vapor pressure in. Hg.	Relative Humidity		Difference in vapor pressures	Wind velocity, in miles per hour §	Precipitation ‖	Computed evaporation, in inches
			Mean of 8 a. m. and 8 p. m.†	Mean ‡				
January	11.6	0.069	80%	81	0.013	7.8	0.90	0.35
February	15.0	0.081	79	79	0.017	8.3	0.84	0.47
March	28.2	0.151	74	75	0.038	8.8	1.60	1.07
April	45.7	0.306	65	66	0.104	9.3	2.33	3.02
May	58.2	0.485	64	65	0.170	8.7	3.12	4.76
June	67.4	0.670	68	67	0.221	7.7	4.41	5.88
July	72.1	0.786	66	¶ 67.5	0.255	7.1	3.40	6.55
August	69.5	0.720	69	69	0.223	7.1	3.46	5.72
September	60.3	0.523	72	72	0.146	8.0	3.42	3.94
October	48.1	0.335	72	73	0.091	8.5	2.34	2.53
November	30.9	0.171	75	76	0.041	8.1	1.30	1.11
December	19.3	0.099	79	81	0.019	7.8	1.06	0.51
Annual	43.9	.....	72	.....	.....	.....	28.68	.....

* Mean of 43 years, 1871 to 1913, inclusive.
† Mean of 24 years, 1888 to 1911, inclusive.
‡ As modified by Minneapolis records.
§ Mean of 36 years, 1873 to 1908, inclusive.
‖ Mean of 43 years, 1871 to 1913, inclusive.
¶ As modified by Minneapolis, Moorhead, and LaCrosse records.

TABLE 3

COMPUTED EVAPORATION, MOUNT HOPE, N. Y.

Month	Temperature		Relative humidity	Maximum Vapor Pressure		Observed vapor pressure in air	Difference in Vapor Pressure		Wind velocity*	Precipitation	Computed evaporation	Actual evaporation
	Air, in shade	Water, in tub		Water temperature	Air temperature		Air temperature	Water temperature				
Jan	24.8	32.5	78.0	0.183	0.129	0.101	0.028	0.082	10.0	1.83	1.21	1.27
Feb	23.3	32.3	77.9	0.182	0.120	0.092	0.028	0.090	10.9	1.49	1.26	1.26
Mar	34.1	35.8	73.9	0.209	0.196	0.145	0.051	0.064	9.8	1.96	1.63	2.35
Apr	46.7	46.6	68.3	0.317	0.318	0.217	0.101	0.100	8.8	2.21	2.82	2.97
May	60.1	59.0	68.1	0.499	0.519	0.354	0.165	0.145	7.8	2.69	3.88	3.64
June	70.5	68.2	68.1	0.689	0.744	0.507	0.237	0.182	7.2	2.47	4.70	4.40
July	74.7	72.6	68.8	0.799	0.858	0.590	0.268	0.209	7.2	3.70	5.40	5.11
Aug	72.1	71.3	71.3	0.765	0.786	0.560	0.226	0.205	6.5	2.91	5.08	4.73
Sept	65.7	65.6	74.6	0.629	0.631	0.471	0.160	0.158	7.2	2.44	4.08	3.63
Oct	53.1	53.8	75.2	0.414	0.404	0.304	0.100	0.110	7.7	2.37	2.73	2.65
Nov	39.9	42.5	76.6	0.271	0.246	0.188	0.058	0.083	8.9	1.97	1.80	1.70
Dec	28.9	34.3	77.9	0.197	0.156	0.122	0.034	0.075	9.5	1.74	1.28	1.56
Annual	49.5	51.2	73.2	.....	.....	.....	.....	.....	....	27.77	.....	....

* Wind velocity according to U. S. Weather Bureau at Rochester, N. Y., 1895 to 1906.

"During the winter months the water in the floating tub was at a surprisingly high temperature, presumably due to the pumping of water into the reservoir in which the tub was floating. It is assumed, therefore, that the layer of air immediately above the water surface was heated to nearly water temperature, and that the most probable value for actual vapor pressure would be secured by applying the relative humidity to the maximum vapor pressure at the water temperature rather than at the air temperature observed some distance above the water surface. It is a fact, illustrated in *Fig. 10, that the average relative humidity varies only very slightly with changes of altitude of several thousand feet. This might be expected, because there is constant diffusion of vapor tending toward equal relative humidities. Tate says that vapor diffuses through the atmosphere much more rapidly than it is formed from the surface of the water, assuming no convection currents present. This rapid diffusion of vapor, even in spite of air currents, must tend strongly toward the maintenance of equal relative humidities at all altitudes.

"Table 4 gives the monthly evaporation † as observed and estimated by Desmond FitzGerald, Past-President, Am. Soc. C. E., at Boston, Mass.

TABLE 4

EVAPORATION AT BOSTON, MASS.

Month.	*Temperature, in degrees, Fahrenheit.	Observed values, 1875–1885.	Observed values, 1875–1890.
January	27	†0.90	†0.96
February	28	†1.20	†1.05
March	34	†1.80	†1.70
April	44.5	†3.10	†2.97
May	58	4.61	4.46
June	67	5.86	5.54
July	71	6.28	5.96
August	69	5.49	5.50
September	62	4.09	4.12
October	52	2.95	3.16
November	40	1.63	2.25
December	30	†1.20	1.51
		39.11	39.20

* Values taken from curve. † Values largely estimated.

"The values in Table 4 are platted in Fig. 11. The similarity between this curve and that of Fig. 8 is apparent.

* Data from *Bulletin F*, U. S. Weather Bureau, 1896.
† *Transactions*, Am. Soc. C. E., Vols. XV and XXVII.

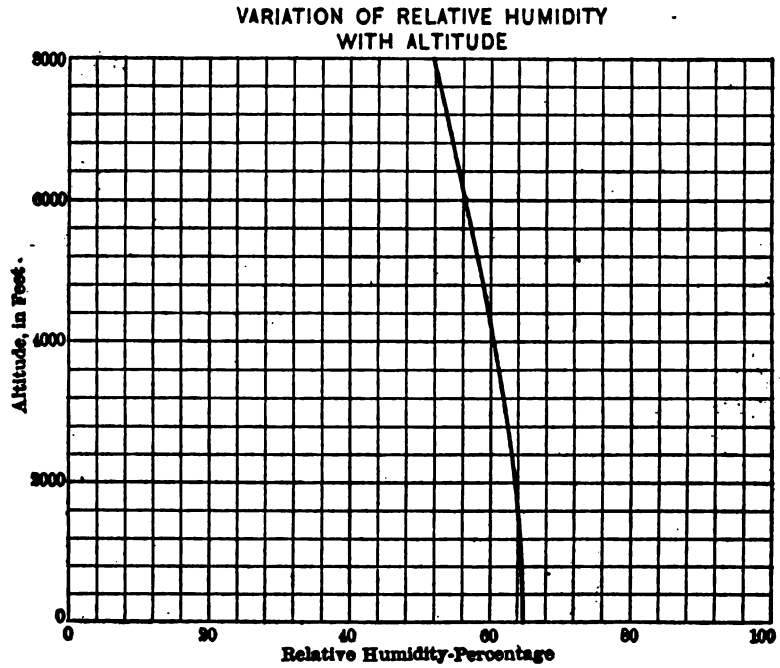

VARIATION OF RELATIVE HUMIDITY
WITH ALTITUDE
8000
6000
4000
2000
0
Altitude, in Feet.
0
20
40
60
80
100
Relative Humidity-Percentage

FIG. 10.

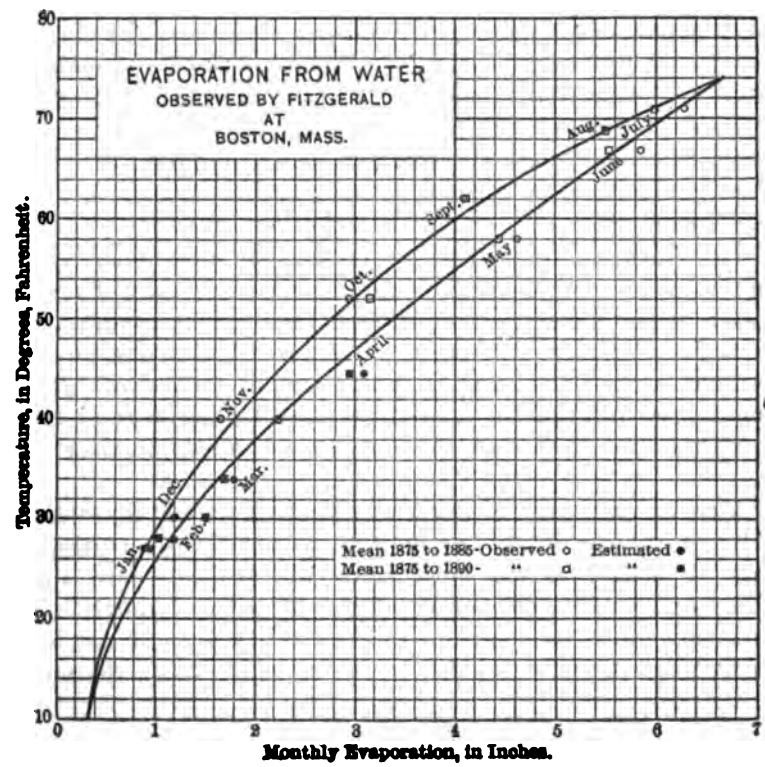

EVAPORATION FROM WATER
OBSERVED BY FITZGERALD
AT
BOSTON, MASS.
80
70
60
50
40
30
20
10
Temperature, in Degrees, Fahrenheit.
Aug.
July
June
Sept.
May
Oct.
April
Nov.
Dec.
Mar.
Jan.
Feb.
Mean 1875 to 1885-Observed ○ Estimated ●
Mean 1875 to 1890- " □ " ■
0
1
2
3
4
5
6
7
Monthly Evaporation, in Inches.

FIG. 11.

"Many other records of evaporation are available, but are omitted here because they do not give the evaporation from shallow water under conditions of wind and humidity prevailing throughout the Northwest.

"The curves in Fig. 12 give the evaporation from open water in lakes of medium size and depth, and also the evaporation from snow and ice surfaces. The high rate of evaporation from snow under certain exceptional conditions has frequently been commented on. The values given are believed to be approximately right for ordinary conditions. The break in the up-going curve results from the fact that relatively large bodies of water remain frozen in spring until the monthly mean temperature has reached about 38 degrees. Until the break-up the evaporation is from snow and ice surfaces, and consequently larger, at the same temperature, than that from the relatively cold water immediately after the break-up. Most bodies of water of moderate size freeze up in the fall, when the monthly mean temperature reaches about 20 degrees.

"Horton gives some observations on evaporation from snow* which check the values indicated by the curves of Fig. 12 very well. A loss of 0.25 in. was recorded during the 9 days from December 26th, 1913, to January 4th, 1914. The mean maximum temperature during this period was 29.5°, corresponding to a monthly mean temperature of about 24 degrees. The recorded evaporation for 9 days corresponds to a monthly evaporation of 0.83 in. The curve of Fig. 12 gives 0.9 in. of evaporation per month at a temperature of 24° under base conditions of wind and humidity. The mean wind velocity during the period of observation was 7.3 miles per hour. The relative humidity recorded by the Weather Bureau for January, 1914, was 78 per cent. These values represent approximately normal conditions for the Northwest.

"Fig. 13 shows the monthly mean, and the mean maximum and minimum temperatures, and the approximate percentage of total precipitation which falls as snow during the various months of the year, at St. Paul and at Moorhead, Minn. For a monthly mean temperature of 23°, the mean of the maximum daily temperatures is approximately 32°, and for a monthly mean temperature of 41°, the mean of the minimum daily temperatures is approximately 32 degrees.

"A certain amount of thawing will occur at midday, when the monthly mean temperature reaches 18 to 20°, consequently, small patches of ground in the open fields will become bare and the evaporation from the water-shed will be reduced accordingly. When the monthly mean temperature reaches 32°, the maximum will be above freezing almost every day in the month. When the monthly

* *Monthly Weather Review*, February, 1914.

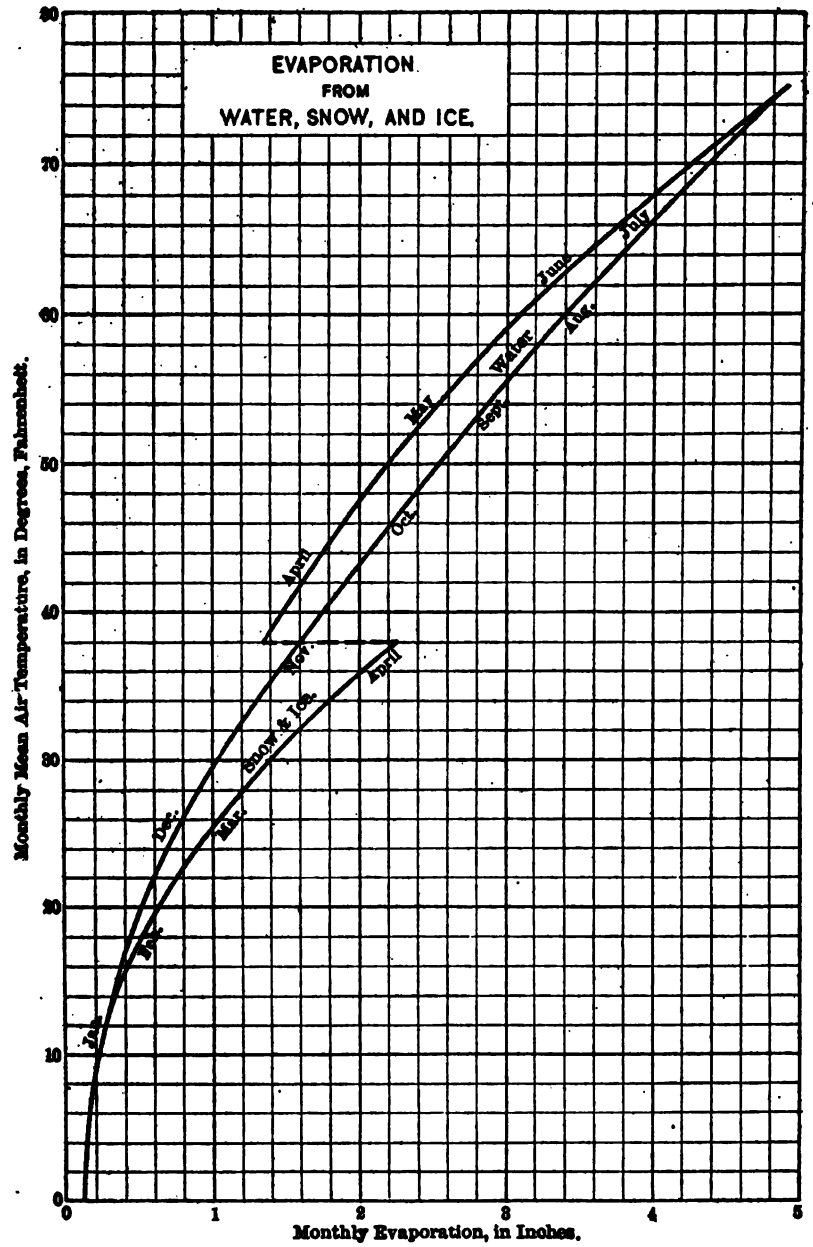

EVAPORATION
FROM
WATER, SNOW, AND ICE.
Monthly Mean Air-Temperature, in Degrees, Fahrenheit.
Monthly Evaporation, in Inches.
0
10
20
30
40
50
60
70
80
1
2
3
4
5
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Snow & Ice.
Water

FIG. 12.

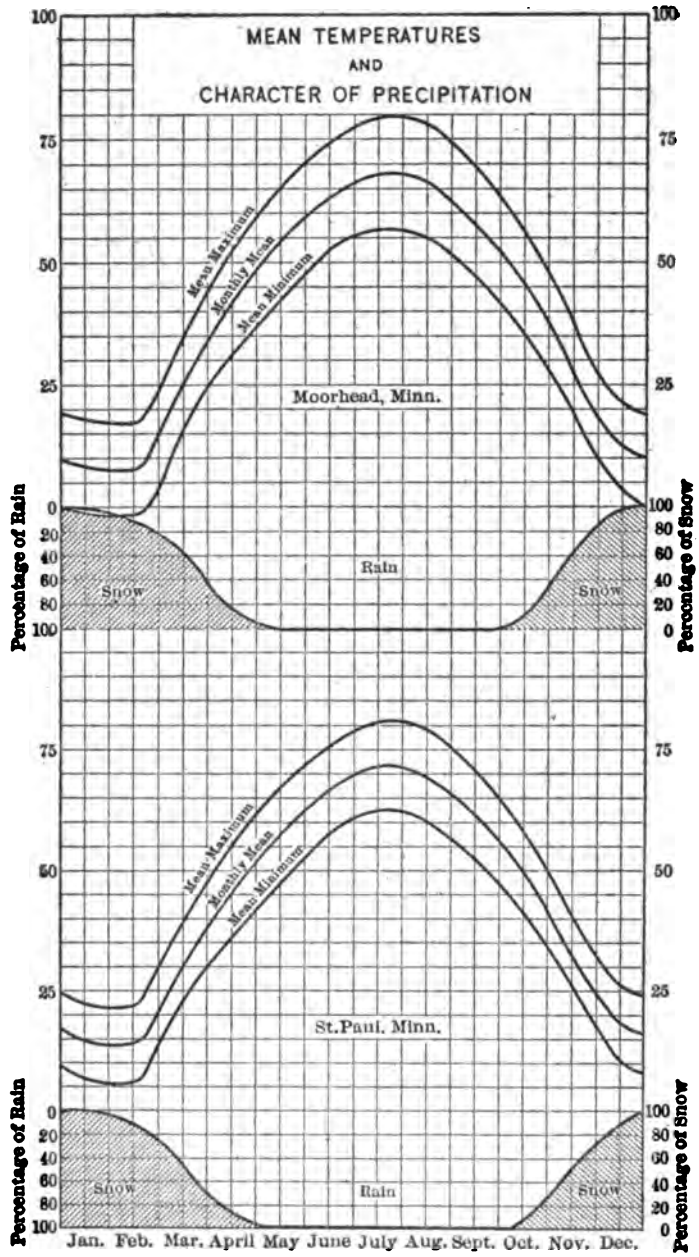

MEAN TEMPERATURES
AND
CHARACTER OF PRECIPITATION
Mean Maximum
Monthly Mean
Mean Minimum
Moorhead, Minn.
Rain
Snow
Snow
Percentage of Rain
Percentage of Snow
St. Paul, Minn.
Jan. Feb. Mar. April May June July Aug. Sept. Oct. Nov. Dec.

FIG. 13.

mean temperature reaches 48°, the minimum will be above freezing almost every day in the month.

"On an average about 30% of the precipitation occurs as snow when the monthly mean temperature is 40°, and practically all of it occurs as snow when the mean temperature is below 20 degrees."

Since Mr. Meyer's paper, from which the above quotation is taken, was prepared, we have secured additional evaporation records taken at University, North Dakota, during 1914. We have also been furnished with observations of evaporation made by the Manitoba Hydrographic Survey at their Keewatin station, from May, 1913, to date. The detailed evaporation records for these two stations, together with records taken at Grand River Lock, Wisconsin, are given in the following pages.

RECORDS OF MANITOBA HYDROGRAPHIC SURVEY, KEEWATIN, ONTARIO.

This station is located on the Lake of the Woods near Keewatin, Ontario. (see the Key Plan of Outlets, Plate 19) The equipment for measuring evaporation consists of a standard pan, three feet square, floated in the Lake by means of a raft. Readings of the temperature of the water in the Lake and in the tank are taken simultaneously with the morning and evening measurements of evaporation. The time of observation averages 7:15 a. m. and 6:30 p. m. during the summer, and 7:45 a. m. and 5:00 p. m. during the winter. Maximum and minimum readings of the temperature of the air are taken, and the true mean daily temperature is also determined by a recording thermometer. Wind velocity, direction of wind, barometric pressure, and relative humidity are also observed at this station.

METEOROLOGICAL DATA—KEEWATIN, ONTARIO

RECORDS OF MANITOBA HYDROGRAPHIC SURVEY

Date	Mean Temperature Degrees F.			Precipitation Inches	Evaporation Inches	Wind Velocity Mi. per Hr.	Relative Humidity Per Cent		
	Lake	Tank	Air				A. M.	P. M.	Mean
1913									
May				1.285	1.365	4.21			
June	59.9	60.8	59.9	2.09	2.35	4.32	59.6	61.4	60.5
July	66.7	66.6	61.3	3.84	3.38	5.48	70.0	66.6	68.3
August	68.2	68.1	62.3	4.27	3.42	4.88	73.7	69.3	71.5
September	62.5	61.5	55.0	1.015	4.080	11.28	81.1	68.9	75.0
October	50.1	49.0	37.8	3.205	(1) 2.155	4.85		80.6	
November	41.0	41.0	31.6	1.35	(2) 0.49	5.04		84.1	
December			20.2			4.31		86.3	
1914									
January	32.0		4.6	1.34		4.76			
February			−4.6	.42		4.35			
March			19.6	.36		5.13			
April	34.7		32.1	1.79	(3) 0.51	4.92	82.9	76.5	79.7
May	42.6	44.9	50.7	1.87	(4) 0.62	6.11	78.3	62.9	70.6
June	59.5	59.6	60.3	4.67	(5) 2.41	7.65	80.8	68.7	74.7
July	70.3	70.5	68.2	3.80	2.46	6.93	84.5	78.9	81.7
August	69.1	69.1		2.07	3.67	4.36	78.6	74.4	76.5
September	60.4	60.3		4.07	(6) 3.01	7.15	84.1	76.4	80.2
October	54.5	54.5	49.9	3.11	2.71	6.66	86.6	83.5	85.0
November	38.3	42.5	27.7	.31	(7) 1.04	8.42	84.6	80.4	82.5
December	32.6		4.3	.40					
1915									
January			.8	.58		3.71			
February			17.3	1.46		3.32			
March	34.1		23.0	.40		6.48		74.9	
April	43.9	42.9	45.5	1.75	(8) .90	7.06	85.4	69.5	77.4
May	49.0	49.5	51.0	2.02	2.00	6.10	80.9	68.0	74.5
June	58.9	59.0	57.6	4.75	1.80	6.56	83.7	80.5	82.1
July	64.7	64.9	62.9	1.65	2.38	5.18	83.8	69.6	76.7
August	68.6	68.5	65.8	1.31	3.29	4.64	81.4	63.8	72.6
September	60.6	60.2	56.1	3.59	2.26	6.62	85.2	65.4	75.3
October	48.4	48.2	45.2	1.01	1.35	7.48	82.7	73.3	78.0
November	38.1	42.2	29.3	1.94	(9) .46	7.71	86.9	77.2	82.0
December	33.1		16.1	1.13		5.46	92.4	84.0	88.2

(1) Evaporation Oct. 1 to 27, inclusive.
(2) Evaporation Nov. 1 to 7, inclusive.
(3) Evaporation Apr. 20 to 30, inclusive.
(4) Evaporation for 13 days.
(5) Evaporation for 25 days. (6) Evaporation for 23 days.
(7) Evaporation Nov. 1 to 13, inclusive
(8) Evaporation Apr. 9 to 30—19 days.
(9) Evaporation Nov. 1 to 11, inclusive.

EVAPORATION AT KEEWATIN, ONTARIO

RECORDS OF MANITOBA HYDROGRAPHIC SURVEY

Date	1913			1914			1915			Mean for period.	
	Air Temp. Deg. F.	Evaporation Inches		Air Temp. Deg. F.	Evaporation Inches		Air Temp. Deg. F.	Evaporation Inches		Air Temp. Deg. F.	Evap. Inches
		* Part Month	Whole Month		* Part Month	Whole Month		* Part Month	Whole Month		
Apr				37.0	0.51	1.39	49.1	0.90	1.42	43.05	1.41
May	† 45.0		1.36	50.7	.62	1.48	51.0		2.00	48.90	1.61
June	59.9		2.35	60.3	2.41	2.89	57.6		1.80	59.27	2.35
July	61.3		3.38	68.2		2.46	62.9		2.38	64.13	2.74
Aug	62.3		3.42	‡ 66.0		3.67	65.8		3.29	64.70	3.46
Sept	55.0		4.08	‡ 56.0	3.01	3.93	56.1		2.26	55.70	3.42
Oct	40.0	2.15	2.47	49.9		2.71	45.2		1.35	45.03	2.18
Nov	37.4	.49	2.10	34.5	1.04	2.40	37.8	.46	1.25	36.57	1.92

* See notes (1) to (9) above.
† Estimated from surrounding stations.
‡ Estimated from Keewatin maximum and minimum daily air temperatures.

NOTE.—Evaporation for the whole month is computed from observed evaporation for part of the month, on the basis of the mean daily rate of evaporation observed during the given portion of the month.
The air temperature given for the different months represents the observed mean temperature for either the whole month or for the portion of the month over which evaporation records extend. (Engrs.)

UNIVERSITY, NORTH DAKOTA

This station is located on the campus of the University of North Dakota, near Grand Forks.

The equipment for measuring evaporation consists of a standard pan, three feet square, floated in a pool in a ravine which runs through the University campus. Except during freshets the flow through the ravine is small, and for several weeks at a time during very dry weather there is merely a succession of pools without any perceptible flow. The pool in which the evaporation gauge is located has a central depth of about 6 feet, and an area of about 0.2 acre. It lies only about 15 feet below the level of the surrounding open prairie, and consequently is fully exposed to the wind.

Records from 1905 to 1912, inclusive, are published in the 1912 "Report of Water Resources Investigation of Minnesota" by the State Drainage Commission, in coöperation with the U. S. Geological Survey. Additional records have been secured from the Washington office of the U. S. Geological Survey; and also directly from Professor E. F. Chandler, under whose supervision the work is being performed. Readings are taken daily about an hour before sunset. During 1905 and 1906 air temperatures were not taken. From 1907 to date the air temperature given herewith is the mean of the observed maximum and the minimum. The mean monthly water temperature is the mean of the daily observations made about an hour before sunset.

The air temperatures given in the following table for the years 1905 and 1906, where observations extend over full months, are the mean monthly temperatures given in the reports of the U. S. Weather Bureau. Where observations extend over only part of the month, the air temperature at University was deduced by taking the mean daily recorded air temperature at Bismarck, N. D., for the days on which evaporation was recorded at University, and then applying to this mean for Bismarck a small correction based on the relation between mean monthly temperatures at University and at Bismarck.

SUMMARY OF MONTHLY TEMPERATURE, PRECIPITATION AND EVAPORATION, UNIVERSITY, NORTH DAKOTA

RECORDS OF UNITED STATES GEOLOGICAL SURVEY

	MEAN TEMPERATURE—DEGREES F.		Precipitation Inches	EVAPORATION INCHES.	
	Air	Water		Part Month	Whole Month
April (17-30) 1905	45	37	0.20	1.78	3.80
1906	48	52	2.09		3.52
(22-30) 1907	34	39	0.05	0.46	1.53
(15-30) 1908	48	39	0.68	2.26	4.25
(20-30) 1909	35	41	0.53	0.89	2.43
(3-30) 1910	46	42	1.13	2.81	3.00
(22-30) 1911	54	51	0.00	1.80	*5.00
(19-30) 1912	44	50	0.78	0.94	2.35
(5-30) 1913	48	50	0.53	3.87	4.45
(16-30) 1914	43	46	1.99	0.95	1.90
Mean	44.5				3.22
May 1905	52	48	3.35		3.48
1906	52	57	3.06		3.68
1907	44	47	0.63		3.48
1908	51	54	3.77		3.83
1909	54	51	2.60		3.84
1910	50	52	0.71		5.08
1911	57	58	3.17		3.71
1912	54	58	2.92		4.98
1913	51	53	1.52		4.23
1914	56	59	2.21		4.86
Mean	52.1				4.12
June 1905	60	58	4.05		3.89
1906	63	69	3.09		4.13
1907	63	65	4.63		4.55
1908	66	67	2.70		3.22
1909					
1910	68	70	0.08		6.95
1911	69	73	4.78		4.33
1912	63	72	0.06		5.79
1913	67	†68	1.21		7.09
1914	63	70	6.51		4.53
Mean	65				4.94
July 1905	66	70	5.48		5.46
1906	66	73	2.56		4.83
1907	66	79	2.91		5.99
1908	69	76	2.47		6.32
1909	67	73	0.96		5.02
1910	72	70	0.76		7.01
1911	65	70	2.06		6.13
1912	67	73	5.29		5.76
1913	66	71	2.86		5.74
1914	71	80	4.19		5.55
Mean	67.5				5.78
August 1905	67	69	4.54		4.02
1906	66	73	1.09		4.92
1907	65	72	1.87		4.53
1908	65	68	2.41		5.77
1909	69	72	2.59		4.19
1910	64	67	0.90		4.76
1911	64	66	3.38		3.99
1912	62	67	2.70		3.94
1913	70	70	1.69		5.29
1914	63	69	3.31		4.60
Mean	65.5				4.60

* The use of the rate of evaporation recorded from April 22nd to 30th would give a monthly evaporation of 6 inches, which is considered excessive. The high rate of evaporation recorded during the last 9 days of April is believed to be due to the lack of precipitation, high winds, and to the averaging of the extremes of temperature which occurred during the latter part of the month. As evaporation varies much more rapidly than temperature, the extension of a rate of evaporation secured from observations covering only a few days to a relatively long period, such as a month, covering wide changes of temperature, always gives too high a monthly value for evaporation.

†Ten days estimated.

SUMMARY OF MONTHLY TEMPERATURE, PRECIPITATION AND EVAPORATION, UNIVERSITY, NORTH DAKOTA

RECORDS UNITED STATES GEOLOGICAL SURVEY

	MEAN TEMPERATURE—DEGREES F.		Precipitation Inches	EVAPORATION INCHES.	
	Air	Water		Part Month	Whole Month
Sept. 1905	60	61	1.62	.....	3.75
1906	63	67	1.61	.....	4.04
1907	53	.....	3.86	.....	3.17
1908	62	58	0.50	.....	4.24
1909	58	58	0.67	.....	3.68
1910	55	58	3.04	.....	3.03
1911	54	55	1.07	.....	2.32
1912	54	56	5.16	.....	4.23
1913	58	59	2.65	.....	3.69
1914	60	62	0.34	.....	4.14
Mean	57.7	.....	.....	.....	3.63
Oct. (1-13) 1905	54	50	0.01	1.37	3.26
1906	44	47	0.58	.....	1.92
1907	44	.....	0.64	.....	1.98
1908	46	42	0.62	.....	1.58
1909	47	41	0.45	.....	1.51
1910	48	48	0.61	.....	3.32
1911	43	47	0.94	.....	1.29
1912	43	40	0.29	.....	1.66
1913	38	38	1.61	.....	1.68
1914	52	53	1.80	.....	2.89
Mean	45.9	.....	.....	.....	2.11
Nov. 1905	.....	.....	.....	.....	.....
1906	.....	.....	.....	.....	.....
(1-10) 1907	36	.....	0.05	0.17	0.51
(1-10) 1908	35	32	0.01	0.19	0.57
1909	.....	.....	.....	.....	.....
1910	.....	.....	.....	.....	.....
1911	.....	.....	.....	.....	.....
(1-9) 1912	33	32	0.05	0.15	0.56
(1-25) 1913	33	32	0.38	0.42	0.50
(1-11) 1914	38	37	0.20	0.39	1.06
Mean	35	.....	.....	.....	0.63

RECORDS OF UNITED STATES ENGINEER OFFICE

GRAND RIVER LOCK, WISCONSIN

This station is located at Grand River Lock, on the Upper Fox River, Wisconsin.

The equipment for measuring evaporation consists of a standard pan, three feet square, supported in a raft which is floated in a shallow slough of water near the Lock. Observations are made twice daily by the lock master, under the direction of Mr. L. M. Mann, U. S. Assistant Engineer, Oshkosh, Wisconsin. Records from 1905 to 1912, inclusive, are published in the 1912 "Report of Water Resources Investigation of Minnesota" by the State Drainage Commission, in coöperation with the U. S. Geological Survey. Additional records subsequent to 1912 have been secured from the U. S. Geological Survey and directly from Mr. Mann.

Where the observed evaporation covers a portion of the month only, as, particularly, in April and November, the value for the whole month was obtained by assuming that the observed daily rate of evaporation at the given temperature continued for a full month. This assumption makes the mean values of temperature and evaporation somewhat larger than they would otherwise be, due to the fact that the portion of the month for which no records were secured was the colder part. It was considered inadvisable to attempt to estimate mean monthly temperature and evaporation by assuming certain temperatures and rates of evaporation for the portion of the month over which the observations did not extend.

In the method used, the estimated monthly evaporation represents the extension of an actual observed rate at an observed temperature for a portion of a month, the only assumption being that the same mean rate would have continued for an additional number of days at the same mean temperature.

SUMMARY OF MONTHLY TEMPERATURE, PRECIPITATION AND EVAPORATION, GRAND RIVER LOCK, WISCONSIN

RECORDS OF UNITED STATES ENGINEER OFFICE

		MEAN TEMPERATURE—DEGREES F.		Precipitation—inches	EVAPORATION INCHES	
		Air	Water		Part Month	Whole Month
April	1907	37	43	2.89	.....	2.32
	1908	46	49	4.59	.....	2.54
(6–30)	1909	39	42	4.14	1.06	1.27
	1910	50	51	4.16	.....	3.11
(10–30)	1911	49	53	1.16	1.96	2.80
(8–30)	1912	47	51	1.20	2.91	3.80
	1913	44	50	2.08	.....	3.94
	1914	.....	.....	.....	.....	.....
	Mean	45	.....	.....	.....	2.83
May	1906	51	58	4.42	.....	3.58
	1907	47	56	2.84	.....	4.29
	1908	55	59	4.95	.....	4.01
	1909	54	59	2.10	.....	4.59
	1910	54	60	2.38	.....	5.53
	1911	61	66	5.33	.....	3.88
	1912	56	61	8.25	.....	4.08
	1913	51	60	6.22	.....	4.88
	Mean	54	.....	.....	.....	4.35
June	1906	62	71	9.48	.....	3.73
	1907	62	71	3.14	.....	5.28
	1908	61	71	3.26	.....	5.37
	1909	64	73	3.30	.....	5.69
	1910	66	72	0.83	.....	5.84
	1911	71	73	3.55	.....	4.58
	1912	60	70	0.69	.....	6.93
	1913	67	75	3.78	.....	6.73
	1914	.....	.....	.....	.....	.....
	Mean	64	.....	.....	.....	5.52
July	1906	66	75	2.77	.....	4.74
	1907	66	75	5.54	.....	5.44
	1908	68	76	1.88	.....	5.60
	1909	66	76	0.40	.....	6.47
	1910	70	74	0.67	.....	6.25
	1911	68	72	2.38	.....	5.45
	1912	67	74	5.18	.....	6.13
	1913	69	73	4.28	.....	5.81
	1914	.....	.....	.....	.....	.....
	Mean	68	.....	.....	.....	5.74
Aug.	(13–31) 1905	65	73	2.60	3.20	5.22
	1906	67	74	6.30	.....	3.97
	1907	66	71	6.65	.....	4.51
	1908	63	71	2.54	.....	5.17
	1909	68	71	3.20	.....	4.94
	1910	62	71	4.22	.....	5.00
	1911	65	71	2.96	.....	3.89
	1912	63	67	6.91	.....	3.78
	1913	68	70	1.44	.....	3.71
	1914	.....	.....	.....	.....	.....
	Mean	65	.....	.....	.....	4.46
Sept.	1905	61	67	3.48	.....	4.06
	1906	61	68	4.15	.....	3.34
	1907	58	62	3.97	.....	3.98
	1908	61	68	1.28	.....	4.21
	1909	58	63	2.49	.....	2.95
	1910	58	64	4.78	.....	3.49
	1911	59	62	4.35	.....	2.66
	1912	58	64	5.52	.....	3.41
	1913	61	63	3.63	.....	2.95
	1914	.....	.....	.....	.....	.....
	Mean	59	.....	.....	.....	3.45

SUMMARY OF MONTHLY TEMPERATURE, PRECIPITATION AND EVAPORATION, GRAND RIVER LOCK, WISCONSIN

RECORDS OF UNITED STATES ENGINEER OFFICE

		MEAN TEMPERATURE—DEGREES F.		Precipitation—inches	EVAPORATION INCHES	
		Air	Water		Part Month	Whole Month
Oct.	1905	52	57	2.50	.....	3.22
	1906	44	50	5.25	.....	1.91
	1907	45	49	.93	.....	2.44
	1908	47	51	1.13	.....	1.92
	1909	43	43	.86	.....	1.84
(1-28)	1910	51	56	.87	2.63	2.92
	1911	46	48	5.60	.....	1.14
	1912	54	51	1.30	.....	2.37
	1913	.....	.....	.....	.....	.....
	1914	.....	.....	.....	.....	.....
	Mean	48	.....	.....	.....	2.22
Nov.	1905	.....	.....	.....	.....	.....
(1-11)	1906	40	41	0.07	0.29	0.79
(1-12)	1907	39	43	0.53	0.46	1.15
(1-10)	1908	39	39	0.06	0.29	0.87
(1-12)	1909	45	47	0.70	0.71	1.77
	1910	.....	.....	.....	.....	.....
	1911	46	48	5.65	.....	1.16
(1-24)	1912	36	38	1.01	0.62	0.78
	1913	.....	.....	.....	.....	.....
	1914	.....	.....	.....	.....	.....
	Mean	41	.....	.....	.....	1.09

The curves of "Evaporation from Water, Snow and Ice, Lake of of the Woods," Plate 14, are based on the temperature and evaporation observed by the Manitoba Hydrographic Survey, on the Lake of the Woods, at Keewatin, Ontario, from 1913 to 1915, and on the general shape of similar curves presented in Mr. Meyer's paper.

The curves, Plate 14, represent the general relationship existent between monthly mean air temperature, relative humidity and wind velocity around the Lake of the Woods, and evaporation from the surface of the Lake, as deduced from observations. It will be perceived that values taken from these curves will, of necessity, differ somewhat from the values observed from month to month and year to year, just as these observed values will differ among themselves to an extent not readily accounted for except by regarding these discrepancies as unavoidable and incident to measurements of complex phenomena of this class.

WATER GAUGES AND BENCH MARKS

Inasmuch as the water levels observed on the various lakes and rivers of the watershed of the Lake of the Woods, during the past years, constitute the most essential records in this investigation, the location, reference marks, zeros, etc., of the various gauges on which such water levels were observed will first be described. The gauges will be taken up approximately in order, beginning with those near the headwaters and proceeding down stream. For the locations of the gauges on Namakan and Rainy Lakes and on Rainy River, see the sketch map facing page 92.

KETTLE FALLS—NAMAKAN LAKE GAUGE

On August 8th, 1912, a staff gauge was installed by the Manitoba Hydrographic Survey on the Canadian mainland shore, at the head of the first narrows above the falls in the Canadian channel. This gauge was bolted into the rock ledge, 25 feet east of B. M. No. 2, described below.

The following instrumental determinations of the zero of this gauge have been made:

By	Date	Gauge Zero Public Works, Canada, Datum
Manitoba Hydrographic Survey	Aug. 8, 1912	497.33
Department of Public Works, Canada	Nov. 5, 1913 (gauge changed from staff to automatic).	496.60
Department of Public Works, Canada	Nov. 1, 1914 (changed on account of rise of Lake Namakan).	497.00

This gauge is referred to the following bench mark:

B. M. No. 2. Top of copper plug cemented into rock on Canadian main shore at head of first Narrows above Kettle Falls, and 25 feet above gauge; referenced by 12 inch poplar blazed and marked 50 ft. W. Elevation, Public Works, Canada, Datum..... 506.50

This gauge is shown on Plate O, and one of the surveyors is pointing out the location of the bench mark by holding a pole on it.

The readings of this gauge appear in Table 51 and on Plates 98 to 99A.

KETTLE FALLS—RAINY LAKE GAUGE

On August 8th, 1912, a staff gauge was installed by the Manitoba Hydrographic Survey on the Canadian mainland shore about 550 yards below the falls in the Canadian channel. The zero of this gauge was determined by water level transfer of Public Works, Canada, datum, from Ranier, Minnesota. This gauge was used by the

Department of Public Works, Canada, until August 11th, 1913, when a temporary and more accessible gauge was established because the gauge reader refused to cross the bay to make the readings.

This temporary gauge was replaced by a permanent gauge on November 5th, 1913. In 1914, a timber crib was built in Rainy Lake below the falls, and a new gauge installed on this crib.

The following instrumental determinations of the zero of this gauge have been made:

By	Date	Gauge Zero Public Works, Canada, Datum
Manitoba Hydrographic Survey	Aug. 8, 1912	487.64
Department of Public Works, Canada (temporary gauge)	Aug. 11, 1913	490.24
Department of Public Works, Canada (permanent gauge)	Nov. 5, 1913	490.50
Department of Public Works, Canada (permanent gauge re-set)	Nov. 1, 1914	490.00

The readings of this gauge appear in Table 32. The gauge is referred to the following bench mark:

B. M. No. 3. On Canadian shore 1500 feet below Canadian Falls.
Elevation, Public Works, Canada, Datum 500.13

RANIER, MINNESOTA

The Rainy Lake gauge at Ranier, Minnesota, was established in August, 1911, by the Department of Public Works, Canada. This gauge consisted of a 12-foot staff located on the easterly side of the Ranier wharf. In the fall of 1912 the destruction of the gauge by boats necessitated re-setting of the gauge, as indicated in the table below.

On December 6th, 1913, an automatic gauge was established on the pier above the Canadian Northern Railroad bridge at Ranier. The readings of the staff gauge, previous to December 6th, 1913, were made twice daily, at 8 a. m. and 6 p. m. The following instrumental determinations of the zero of this gauge have been made:

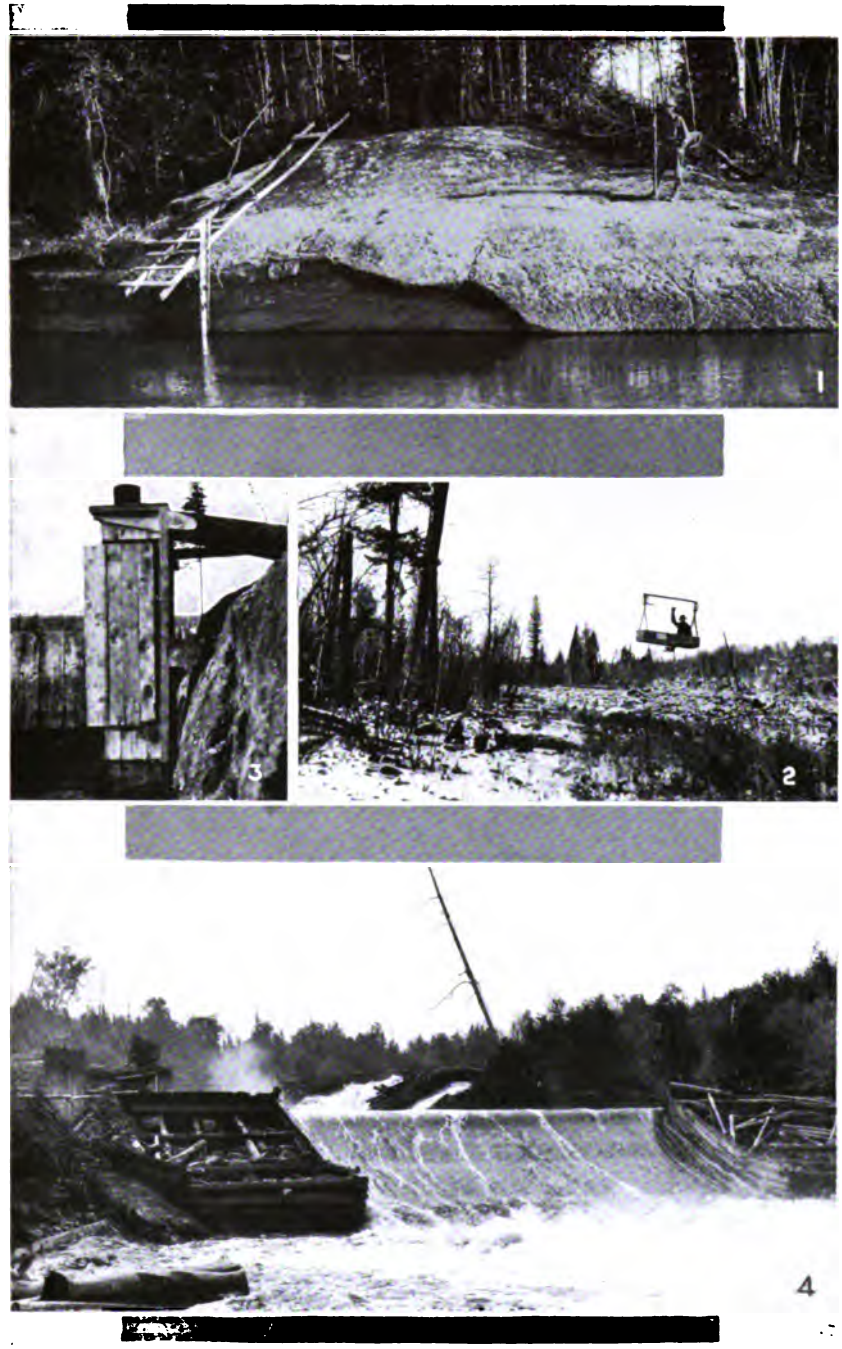
	Elevation Public Works, Canada, Datum
Aug. 20, 1911, Zero of staff gauge as established by the Department of Public Works, Canada	489.00
Sept. 21, 1912, Zero of staff gauge (gauge re-set)	488.77
[1] Oct. 15, 1912, Zero of staff gauge (gauge re-set)	489.25
Dec. 6, 1913, Zero of automatic and staff gauges	488.00

In July, 1913, the zero of the old gauge on the Ranier dock was found, by the International Boundary Commission, to be 1100.70 sea-level datum, or 489.09 Public Works, Canada, datum.

In the spring of 1915 it was found that at low stages and high rates of outflow the automatic gauge gave readings considerably too low.

[1] On Oct. 10th, 1912, the gauge reader reported "Gauge out of commission."

PLATE O



1. NAMAKAN LAKE GAUGE AT KETTLE FALLS: MAN HOLDING POLE ON B. M. SEPTEMBER 13, 1913
2. CABLE AND CAR AT KAWISHIWI METERING STATION.
3. ORIGINAL INSTALLATION OF AUTOMATIC GAUGE ON KAWISHIWI RIVER NEAR WINTON
4. DAM ON KAWISHIWI RIVER WITH AUTOMATIC GAUGE SHELTER (NOT VERY CLEAR) AT LEFT

Consequently, another automatic gauge was established at the Northern Construction Company's mill farther up in the Lake.

The readings of the Rainy Lake gauges appear in Tables 31 and 31A, and are shown graphically on Plates 90 to 92.

The Ranier gauge is referred to the following bench marks:

B. M. No. 8. Located on north side of west abutment 1 foot from C. N. R. bridge. Elevation, Public Works, Canada, Datum..... 502.27

B. M. No. 9. Cut in stringer near end of high level on east side of small wharf at the end of Main Street, above Ranier. Elevation, Public Works, Canada, Datum..... 498.14

In 1913 the International Boundary Commission established the following bench mark:

Ranier, Minn. on shore of Rainy Lake, 6 ft. back of waters edge; 85 ft. west of boat shop, since burned; 150 feet east of mill building covered with metal; 200 ft. west of pier in Lake, foot of Main Street; in top of flat outcrop of rock. Bronze tablet stamped (1111) ft. Elevation Sea-level, Datum (U. S. C. and G. S. 1912 adjustment)..... 1110.690

UPPER POWER HOUSE GAUGE—FORT FRANCES, ONTARIO

In August, 1911, the Department of Public Works, Canada, established a gauge above the Canadian Power House for the purpose of obtaining forebay levels. The elevation of the top of a steel girder located at the center of the power house wall was determined, and measurements are taken to the water surface from this point. The readings are taken three times daily, at 8 a. m., 1 p. m., and 6 p. m.

Elevation, top of girder, Public Works, Canada, Datum..... 501.75

The readings of this gauge appear in Table 33, and on Plates 90 to 92.

Public Works, Canada, Datum, at Fort Frances, Ontario, is fixed by what is known as the "500" bench mark, described as follows:

Department of Public Works, Canada, B. M. Top of iron bolt set vertically in solid rock, 4 feet from edge of north side of canal, directly beneath the Canadian end of the Minnesota and Ontario Power Company's bridge:

Elevation, Public Works, Canada, Datum..... 500.00
Elevation, Sea-level Datum..... 1111.61

A picture of this bench mark is shown on Plate Q.

There is also a permanent bench mark at International Falls, Minnesota, being:

United States Geological Survey, B. M. stamped 1126. Aluminum tablet in ledge of solid rock, 300 feet north of First Street, in line with Third Avenue and 200 feet west of American end of Minnesota Ontario Power Company's bridge:

Elevation, Public Works, Canada, Datum..... 512.763
Elevation, Sea-level Datum..... 1124.376

Elevations referred to Public Works, Canada, Datum can be reduced to sea-level datum by the addition of 611.61.

UPPER PULP MILL GAUGE—INTERNATIONAL FALLS, MINN.

About March 1st, 1907, the Minnesota & Ontario Power Company established a gauge in quiet water in Rainy River, above Koochiching Falls, on cofferdam "B", near the Fort Frances shore. During the latter part of 1908, or the early part of 1909, this gauge was moved to cofferdam "E", near the middle of the River, directly out from the first location. Both gauges are reported to have been located in quiet water. These earlier gauges were read frequently by the Power Company, although not always daily. For the location of cofferdams, see "Map of Koochiching Falls in State of Nature," Plate 76.

Upon completion of their U. S. grinder plant, the Minnesota & Ontario Power Company installed a 15 foot staff gauge, reading directly to Public Works, Canada, datum. The gauge was bolted to the northeast corner of the grinder room, and is of permanent character. A picture of this gauge is shown on Plate S. This gauge is read daily, except Sunday, by the Minnesota & Ontario Power Company, and also three times daily by the gauge reader of the Department of Public Works.

The readings of these gauges appear in Table 36, and on Plates 88 to 92.

LOWER POWER HOUSE GAUGE

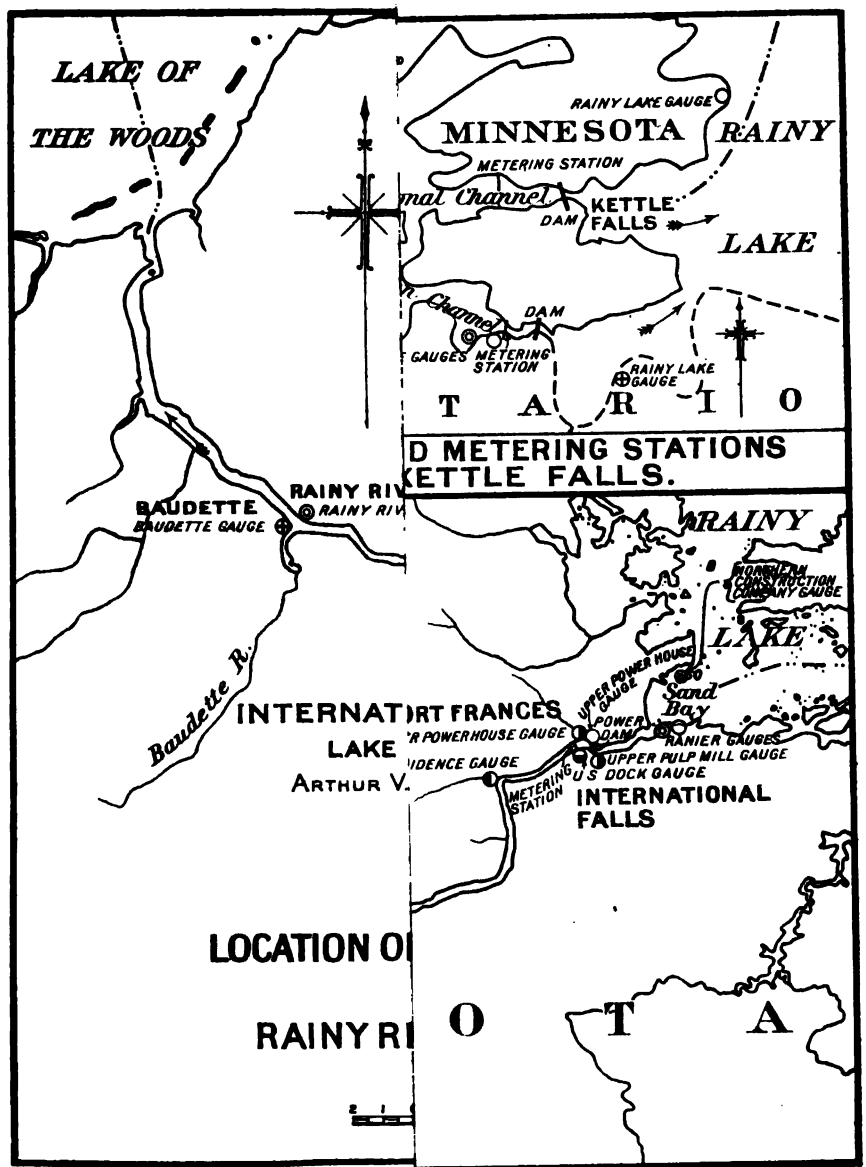
On March 1st, 1907, the Minnesota & Ontario Power Company established a gauge below Koochiching Falls, and from that date on frequent, although not always daily, readings were taken of this gauge. The gauge is reported to have been fastened to the cofferdam below the uncompleted wheel pits of the United States portion of the plant, and to have been below any direct influence from the Falls.

About May, 1910, the Minnesota & Ontario Power Company established the present lower power house or tail water gauge by bolting a graduated staff to the downstream side of the dam, ten feet north of the Canadian log sluice. This gauge consists of a 20 foot staff, reading directly to Public Works, Canada, datum. The gauge is read daily by the Company, and three times daily by the Department of Public Works, Canada.

The readings of these gauges appear in Tables 34 and 36, and are shown graphically on Plates 93 to 97.

U. S. GEOLOGICAL SURVEY GAUGE ON DOCK—INTERNATIONAL FALLS, MINN.

On April 20th, 1911, a staff gauge was established by engineers of the United States Geological Survey, on a pile at the northwest corner of the river dock below International Falls, and about 2000 feet below the Minnesota and Ontario Power Company's dam.



98896—17. (Face page 92.)

This gauge was read daily by the gauge reader of the Geological Survey from its installation up to August 24th, 1914, when the readings were discontinued. Beginning with August 14th, 1911, the Department of Public Works, Canada, has read this gauge three times daily. A staff gauge was used until September 15, 1913, when a Stevens automatic recording gauge was installed, by the Department of Public Works, Canada, coöperating with the United States Geological Survey, and the staff gauge has since been used merely as a check on the automatic. A picture of these gauges is shown on Plate S.

The readings of this gauge appear in Tables 35 and 37, on Plates 95 to 97.

On May 22nd, 1911, about a month after the establishment of the staff gauge, an iron bolt was set in bed rock a short distance below the U. S. Dock at International Falls, Minnesota, to serve as the "initial point" of the metering section. A line of levels was run by engineers of the Department of Public Works, Canada, between the 500 bench mark at Fort Frances and this iron bolt, and its elevation found to be 469.73. In August, 1911, a line of check levels was run by the same Department and the elevation found to be 469.74.

On June 8th, 1911, engineers of the United States Geological Survey ran a line of levels from a bench mark at elevation 473.10, to the U. S. Dock gauge and determined the gauge zero to be 460.865, Public Works, Canada, datum. This bench mark is described as a cross on the rock bank at the old meter section on the United States side opposite the island and several hundred yards below the gauge.

It has been stated that the zero of the staff gauge on the dock is usually tied in to the bolt constituting the "initial point", at the time of each metering. From records of meterings secured from various sources, it appears that previous to June, 1912, a gauge zero of 460.76 was generally used, and that from June, 1912, to December 31st, 1914, a gauge zero of 460.79 was used for reduction of gauge heights to Public Works, Canada, datum.

RAINY RIVER GAUGE—GILLON'S RESIDENCE

During the progress of surveys of the Rainy River, a staff gauge was established by the Department of Public Works, Canada, on a small wharf in front of D. J. Gillon's residence, about three miles below Fort Frances. This gauge was read daily during July, August, September, and October, 1914. The zero of the gauge is 459.33, Public Works, Canada, datum.

The readings of the gauge appear in Table 39.

RAINY RIVER GAUGE—LITTLE FORKS, ONTARIO

A Haskell automatic recording gauge was established by the Department of Public Works, Canada, in 1914, at Little Forks, Ontario, a short distance above the mouth of the Little Fork River, and has been in operation continuously since June 1st, 1914.

Zero of gauge, December 31st, 1914, is 457.00, Public Works, Canada, datum. The readings of this gauge appear in Table 40.

RAINY RIVER GAUGE—BIG FORK, ONTARIO

A staff gauge was established by the Department of Public Works, Canada, on September 20th, 1911, at Big Fork, Ontario, a short distance above the mouth of the Big Fork River. The gauge consisted of a 12-foot staff located on a pile at the southwest side of the Big Fork dock. Daily readings of this gauge were taken for a short period in 1911, and, except during the winter of 1913–1914, continuously since May 1st, 1912.

Zero of gauge, December 31st, 1914, Public Works, Canada, Datum	458.00
B. M. No. 21, on elm tree about 150 feet below Big Fork Dock, Elevation, Public Works, Canada, Datum	478.24

The readings of this gauge appear in Table 41, and are shown graphically on Plates 102 to 104A.

RAINY RIVER GAUGE—EMO, ONTARIO

A staff gauge was established by the Department of Public Works, Canada, in 1911, at Emo, Ontario. The gauge consists of a 15-foot staff located on a pile near the southwest corner of the Emo dock.

Readings of this gauge have been taken by the Department of Public Works, Canada, at irregular intervals since September, 1911. Readings of this gauge were taken by the Manitoba Hydrographic Survey during the fall of 1912, and the winter of 1912–1913.

	Elevation Public Works, Canada, Datum
Zero of Gauge as established in 1911	457.53
Oct. 6, 1912, Zero of Gauge (Gauge re-set)	455.37
Mar. 22, 1913, Zero of Gauge	455.40
Aug. 1, 1914, Zero of Gauge (Gauge re-set)	455.80

	Elevation Public Works, Canada, Datum
B. M. No. 30 On small elm, in field opposite head of first island above Emo	467.90
B. M. No. 31 On small spruce below clump of trees near upper end of Emo	467.60

The readings of this gauge appear in Tables 42 and 43, and are shown graphically on Plates 102 to 104A.

UPPER LONG SAULT RAPIDS GAUGE—RAINY RIVER—BIRCHDALE, MINNESOTA

A staff gauge was established by the Department of Public Works, Canada, on October 4th, 1911, at Birchdale, Minnesota, above the Long Sault Rapids. The gauge consists of a 12 foot staff located on the south side of the rock filled crib in the center of the Rainy River above the Rapids.

Daily readings of this gauge have been taken by the Department of Public Works during the open season from October, 1911, to December, 1913, and continuously since April 5, 1914.

	Elevation Public Works, Canada, Datum
December 31, 1914, Zero of gauge	446.00
B. M. No. 39 Top point of upright boulder, appearing as pinnacle of tower, just above first rapid	461.03
B. M. No. 39A Bolt in plate at N. E. corner of pier	458.57
B. M. Nail in cone of root of poplar tree on river bank near Ogren's Landing	459.65
June 26, 1915, Zero of gauge	446.05
Zero of temporary gauge on observer's dock	446.29

The readings of this gauge appear in Table 44, and are shown graphically on Plates 102 to 104A.

LOWER LONG SAULT RAPIDS GAUGE—RAINY RIVER—BIRCHDALE, MINNESOTA

A staff gauge was established by engineers of the International Joint Commission, on March 26th, 1914, at Birchdale, Minnesota, below the Long Sault Rapids. The gauge consists of three, 3-foot sections of enamelled metal gauge nailed to a 2 x 6 stud which is securely attached to the cribwork of the wing pier extending out from the Minnesota side at the foot of the Rapids.

Daily readings of this gauge have been taken by the gauge reader of the International Joint Commission, since April 1st, 1914.

Mar. 26, 1914, Zero of Gauge Public Works Datum	444.00
B. M. Highest point on rock 3 feet in diameter, between two poplar stumps back of shanty at end of pier. Elevation, Public Works, Canada, Datum	457.60

The readings of this gauge appear in Table 45, and are shown graphically on Plates 104 and 104A.

RAINY RIVER GAUGE—BOUCHERVILLE, ONTARIO

A staff gauge was established by the Department of Public Works, Canada, in October, 1911, at Boucherville, Ontario. This gauge consists of a 12-foot staff, located on the southwest side of the Boucherville dock.

Daily readings of this gauge have been taken by the Department of Public Works, Canada, during the open season since 1911, although in 1913 the readings are not entirely continuous.

Dec. 31, 1914, Zero of Gauge. Public Works, Canada, Datum..... 443.00
B. M. No. 43 Top of upstream pile of second row below Boucherville dock. Elevation Public Works, Canada, Datum..... 450.42

The readings of this gauge appear in Table 46, and are shown graphically on Plates 102 to 104A.

RAINY RIVER GAUGE—PINEWOOD, ONTARIO

A staff gauge was established by the Department of Public Works, Canada, on July 13th, 1914, at Pinewood, Ontario. Daily readings of this gauge have been taken since its installation by this Department.

The readings of this gauge appear in Table 48.

Dec. 31, 1914, Zero of Gauge—Public Works, Canada, Datum..... 443.70

RAINY RIVER GAUGE—RAINY RIVER, ONTARIO.

A staff gauge was established by the Department of Public Works, Canada, at Rainy River, Ontario, on May 11th, 1912. This gauge consists of a 9-foot staff located on a pile near the west side and underneath the Rainy River dock near the River View Hotel.

In July, 1913, a Haskell automatic recording gauge was installed on the same dock and the old staff gauge replaced by a new one.

Daily readings have been taken at this station by the Department of Public Works, Canada, since its installation, except for a period of irregular readings during the latter part of 1913 and the early part of 1914.

May 11, 1912, Zero of Gauge. Public Works, Canada, Datum..... 438.63
July, 1913, Zero of Gauge (staff gauge reset and automatic gauge installed) Public Works, Canada, Datum..... 443.00
B. M. No. 56 On brass plug near S. E. corner of cement power house above Rainy River wharf, Elevation Public Works, Canada, Datum..... 454.28
B. M. No. 57 Small nut in center of top of hydrant on first corner above River View Hotel, Elevation Public Works, Canada, Datum..... 457.11

The readings of this gauge appear in Table 47 and on Plates 102 to 104A.

RAINY RIVER GAUGE—BAUDETTE, MINNESOTA

A gauge was established by the Manitoba Hydrographic Survey, on August 16th, 1912, at Baudette, Minnesota. This gauge was read daily by the Manitoba Hydrographic Survey until the freeze-up, and then weekly up to February 9th, 1913.

Aug. 16, 1912. Zero of Gauge Public Works, Canada, Datum..... 445.24

The readings of this gauge appear in Table 49, and are shown graphically on Plates 102 and 103.

VERMILION LAKE GAUGE—TOWER, MINNESOTA

On October 9th, 1913, a staff gauge was established by engineers of the International Joint Commission, on Lake Vermilion, at the city of Tower, Minnesota.

This gauge consists of a vertical staff reading from 0 to 6 feet, nailed to a pile on the north side of the Duluth & Iron Range Railroad Company's dock, which is about 500 feet north of the Cook & Ketcham Lumber Company's saw mill. Except for a short period in the spring of 1914, when it was impossible to read the gauge on account of logs, daily readings have been taken of this gauge since its establishment.

The gauge was set to an assumed datum, and is referred to the following bench marks.

	Feet.
B. M. No. 1. On rock outcrop 3 feet wide, 80 paces east of gauge, between side tracks, and 35 paces south from center of north tracks, marked with paint "B. M. 1." Elevation above zero of gauge	9.13
B. M. No. 2. On small 18″ rock outcrop 6 feet northwest of B. M. No. 1, marked with paint "B. M. 2." Elevation above zero of gauge	8.10
B. M. No. 3. On small rock outcrop 15 paces west of B. M. No. 1, marked with paint "B. M. 3." Elevation above zero of gauge	7.68
B. M. No. 4. On rock 5′x2′ located at water's edge, and 20 paces west of B. M. No. 1, marked with paint "B. M. 4." Elevation above zero of gauge	4.82

The gauge zero was checked on May 23rd, 1914, and found to be correct.

The readings of this gauge appear in Table 52.

BIG FORK RIVER GAUGE—BIG FALLS, MINN.

This station was established on August 27th, 1909, by Mr. G. A. Gray, of the United States Geological Survey. A staff gauge was fastened to a pile at the upstream side of the right hand end of the approach to the Minnesota & International Railroad bridge. The zero of the gauge was checked on April 5th, 1911, and found to be correct.

Logs interfered to such an extent with the relation of discharge to gauge heights that on June 10th, 1911, a new gauge was fastened to an overhanging stump on the left bank of the river about 500 feet below the foot of the rapids. This gauge was referred to the following bench marks.

	Feet.
B. M. No. 1. Highest point on granite boulder 38′ downstream from the gauge—top of bank. Elevation above zero of gauge	18.03
B. M. No. 2. Nail driven flush in stump—top of bank 20′ back from gauge. Elevation above zero of gauge	15.74

Readings were taken of both gauges for some time in order to determine the relation between gauge heights at the two points on the stream. Because of the effect of log jams, however, it is doubtful whether the ascertained correlation holds under all conditions.

On June 11th, 1911, a cable with car for making meter measurements was erected about ¼ mile below the new gauge. Prior to this date discharge measurements had been made from the railroad bridge which makes a decided angle with the stream.

The zero of the gauge was checked on February 24th, 1912, and on June 15th, 1912, by engineers of the U. S. Geological Survey, and a change of .02 foot made in the gauge on the latter date.

Because of the prevalence of log jams on this stream, which nullified the normal relationship between gauge height and discharge, gauge readings were discontinued at this station on September 30th, 1912. Occasional discharge measurements, however, have since been made, as funds permitted.

The records of discharge measurements appear in Table 66, and the daily discharge records in Table 80.

LITTLE FORK RIVER GAUGE—LITTLE FORK, MINNESOTA

This station was established in 1909 by Mr. J. C. Hoyt, of the United States Geological Survey, at the lower of the two highway bridges crossing the Little Fork River near Little Fork post office.

A staff gauge, reading from 5 to 11 feet, was fastened to the piling of the downstream left abutment of the bridge, and referred to the following bench marks.

	Feet.
B. M. No. 1. Nail head in 12 inch stump at the left end of bridge one rod from approach on the downstream side of river bank. Elevation above zero of gauge	19.51
B. M. No. 2. Nail head in stump 5 feet nearer the bridge than B. M. No. 1. Elevation above zero of gauge	20.39
B. M. No. 3. Nail driven horizontally into second pile from upstream side of second trestle bent from left end of bridge. Nail about 3 feet from ground. Elevation above zero of gauge	18.10

A new sectional gauge, reading from 3 feet to 18 feet, was installed on April 4th, 1911.

The zero of the gauge was checked on August 26th, 1909, April 4th, 1911, June 14th, 1912, May 1st, 1913, July 30th, 1913, May 16th, 1914, August 14th, 1914, and March 27th, 1915. A small correction was made in the upper sections of the gauge on June 14th, 1912, August 14th, 1914, and March 27th, 1915.

All gauge heights affected by changes in the datum of some of the gauge sections were corrected in accordance with the errors found.

The records of discharge measurements appear in Table 65, and the daily discharge records in Table 79.

VERMILION RIVER GAUGE—OUTLET OF LAKE VERMILION

This station was established May 17th, 1911, by Mr. Robert Follansbee, of the United States Geological Survey, in the rapids 200 feet below the low timber and rock fill dam, at the outlet of the Lake.

PLATE P

PARTIALLY DESTROYED DAM AT OUTLET OF LAKE VERMILION—1914

LOGGING DAM AT OUTLET OF GARDEN LAKE—1914

COMPLETED DAM IN CANADIAN CHANNEL AT KETTLE FALLS

A staff gauge reading from 0 to 6 feet was attached to an overhanging tree and to a rock on the left bank of the stream. It was referred to the following bench marks.

	Feet.
B. M. No. 1. Nail bent over in tree to which cable is attached on left bank. Elevation above zero of the gauge	4.98
B. M. No. 2. Two nails in root of 6 inch poplar tree to which cable is looped. Left bank of river. Elevation above zero of the gauge	3.66
B. M. No. 3. Cross on flat rock 6 feet by 5 feet by 2 feet high on right side of portage train 3 feet from tree to which cable is attached. Elevation above zero of the gauge	5.24

The zero of the gauge was checked on January 16th, 1912, October 16th, 1912, July 2nd, 1913, October 7th, 1913, and May 20th, 1914. An error of .08 feet was found in the gauge zero on October 7th, 1913. The error resulted from the breaking of one of the braces holding the gauge in position. The gauge was replaced with its zero at the original elevation. The error was distributed over the period since the last preceding check, because the exact date of the breaking of the brace had not been recorded by the observer.

Discharge measurements are made from a cable a short distance below the gauge except at high water, when they are made from a boat about a mile down stream. The records of discharge measurements appear in Table 64, and the daily discharge records in Table 81.

KAWISHIWI RIVER GAUGE—NEAR WINTON, MINNESOTA

A Stevens automatic recording gauge was established during the latter part of September, 1912, by the International Joint Commission, coöperating with the United States Geological Survey, at Kawishiwi Falls, 2½ miles east of Winton, Minnesota. This gauge was located at a point on the right bank of the Kawishiwi River about 500 feet above Fall Lake, and in the pond just above the St. Croix Lumber Company's dam at Kawishiwi Falls. The Kawishiwi River at this point connects Garden and Fall Lakes. A photograph of the original installation, together with one of the cable and car used in making discharge measurements is shown on Plate O. A staff gauge, fastened to the gauge shelter, furnishes a check on the automatic gauge. Later in 1913, the Stevens gauge was replaced by a Friez gauge.

During the high water of June, 1914, the lower part of the installation, together with the float and weight, was carried away by floating logs. The location of the gauge was changed and a concrete well was built slightly below the dam, in a spot protected from floating logs and debris, and connected with the pool above by a pipe through the dam. The missing parts of the automatic gauge were replaced, and the new gauge put in operation about July 1st, 1914. A photograph of the present installation is shown on Plate O.

The gauge is set to an assumed datum, the zero of which is 0.12 foot below the crest of the dam. It is referred to the following bench marks.

	Feet.
B. M. No. 1. Top large rock about 12 feet southeast of B. M. No. 2, and about 60 feet northeast of gauge. Elevation above gauge zero	8.16
B. M. No. 2. Top large cone-shaped rock, 56 feet northeast of old gauge. Elevation above gauge zero	11.10

The zero of the gauge was checked on April 28th, 1913, and on May 22nd, 1914, and found correct.

The gauge is visited weekly by the gauge reader, who changes the recording sheet and reads the staff gauge as a check on the automatic. During the winter the automatic gauge is not operated, and weekly readings, only, of the staff gauge are obtained. However, this gives an accurate record of flow, as the gates at the logging dam are not manipulated during the winter months. The weekly sheets are sent to the St. Paul Office of the U. S. Geological Survey, where the daily discharge is worked up.

The records of discharge measurements appear in Table 67, and the daily discharge records in Table 82.

LAKE OF THE WOODS GAUGE—OAK POINT NEAR MOUTH OF RAINY RIVER, MINNESOTA

A staff gauge was established at Curry's wharf at Oak Point, near the mouth of Rainy River, by the late Mr. F. D. Granger of the International Boundary Commission, in July, 1913, with a zero of 1056.90 sea-level datum. This gauge was read three times daily from July 28th, to October 20th, 1913.

From July 20th, to November 18th, 1914, a gauge, with its zero at 1057.98, was also maintained at Oak Point by the engineers of the International Joint Commission, readings being taken twice daily.

A picture of this gauge is shown on Plate S.

During June, 1914, while dredging operations were in progress near the mouth of Rainy River, a gauge with its zero at 447.20 Public Works, Canada, datum, was maintained, in the same location, by the Department of Public Works, Canada. Daily readings of this gauge were taken only during June, 1914.

The International gauges were referred to the following temporary bench marks. No really permanent objects were found on Oak Point, which is now a sandy island.

T. B. M. No. 1. Nail driven horizontally in one of largest poplar trees back of Mr. Curry's house about 300 feet north of gauge. Elevation Sea-level Datum	1066.47
T. B. M. No. 2. Nail driven vertically in cone on poplar tree a few feet east of B. M. No. 1. Elevation Sea-level Datum	1066.88

The readings of these gauges appear in Tables 17, 19, and 50.

LAKE OF THE WOODS GAUGE—OAK ISLAND, MINNESOTA

A staff gauge was established by the late Mr. F. D. Granger, of the International Boundary Commission, at Oak Island, Minnesota, in June, 1912. Readings of this gauge were taken three times daily by the Boundary Commission during the field seasons of 1912 and 1913, and twice daily by the International Joint Commission during the field season of 1914. The zero of this gauge was determined during the correlation of gauges in October, 1912, and in March, 1914. See Plates 16 and 17. A picture of the gauge is shown on Plate S.

Zero of Gauge. Elevation Sea-level Datum..... 1054.60

P. B. M. Copper plug surmounted by flat plate leaded into highest point of rock 89 feet west of gauge and about 10 feet back from water's edge. Elevation Sea-level Datum..... 1064.40

The readings of this gauge appear in Tables 16 and 18.

LAKE OF THE WOODS GAUGES—WARROAD, MINNESOTA

The several gauges which were installed at Warroad, Minnesota, and read at various times in the past, will be described in connection with the discussion of "Observed Lake Levels". The readings of these gauges appear in Tables 8 and 15, and are shown graphically on Plates 42 to 50.

The following are the principal bench marks at Warroad, Minnesota:

International Joint Commission B. M. in school yard. Top of copper plug in concrete block, carried below frost line, and located near fence, in front of and to the west of new school house. Established October 3rd, 1912. Elevation, Sea-level Datum..... 1068.797

U. S. Engineer B. M. 303. 1100 feet east of Lake Street crossing of Canadian Northern Railway, 145 feet east of Mr. Moody's residence, 40 feet north of edge of river and 55 feet southeast of corner of outbuilding on Mr. Moody's grounds.

Top of cap of iron post B. M. 303, Oct. 1, 1912, Elevation, Sea-level Datum..... 1065.956

Tile B. M. 303, Oct. 1, 1912, Elevation, Sea-level Datum..... 1062.021

United States Geological Survey B. M. 1069. 39 feet southwest of crossing of Lake and State Streets, on public school grounds, 163 feet east of school house. Iron post stamped "1069". Elevation, Sea-level Datum..... 1067.840

Canadian Geodetic Survey B. M. 12-E. In west foundation wall of Warroad post office, 5 inches below concrete blocks and 6 feet 3 inches from southwest corner of building. This is a concrete block building on the north side of Lake Street about 400 feet east of the Canadian Northern Railway.

Elevation, Canadian Geodetic Survey Datum..... 1070.087

Elevation, Sea-level Datum..... 1069.903

LAKE OF THE WOODS GAUGES—KENORA, NORMAN, AND KEEWATIN, ONTARIO

The several gauges which were installed in the Lake, and in the forebays and tailraces of the mills and power plants at the various outlets of the Lake from time to time, will be described in connection with the observed lake and tail water levels. The readings of these gauges appear in Tables 6, 7, 9 to 14, 20, and 22, and are shown graphically on Plates 39 to 67.

The following are some of the principal bench marks in the vicinity of the outlets of the Lake of the Woods:

Description.	Elevation Sea-level Datum.
AT KENORA.	
W. P. S. B. M. 223. 300 feet N. E. from Kenora power house	1045.01
W. P. S. B. M. "A". In concrete floor at N. W. corner of Kenora power house	1047.19
W. P. S. B. M. "B". At base of tower 60 feet N. E. from Kenora power house	1065.41
W. P. S. B. M. "C". 50 feet north of west abutment of Kenora traffic bridge	1067.65
W. P. S. B. M. "D". On S. E. corner of C. P. R. subway at Kenora	1089.41
AT NORMAN.	
W. P. S. B. M. "F". On S. W. corner of east abutment of Norman traffic bridge	1063.58
W. P. S. B. M. "G". On south side of east abutment of bridge over Western Outlet	1063.57
W. P. S. B. M. "J". In rock at south abutment of Norman Dam	1063.50
W. P. S. B. M. "L". In rock at north abutment of Norman Dam	1051.95
Keewatin Power B. M. On top of fishway abutment of Norman dam, marked ⊙ 104.37	1064.35
W. P. S. B. M. "H". On south shore of West Branch of Winnipeg River at metering section, North Tunnel Island	1044.37
Initial Point. North Tunnel Island meter section	1041.19
AT KEEWATIN.	
W. P. S. B. M. "M". East side of south abutment of Keewatin River bridge	1044.91
W. P. S. B. M. "N". 60 feet N. E. Mill "A" power house	1044.19
W. P. S. B. M. Top of flume abutment, Mill "C"	1064.62
C. P. R. B. M. At Keewatin. C. P. R. Elevation 1092.89	1088.68
W. P. S. B. M. "R". At south end Keewatin lake bridge	1069.90

WINNIPEG RIVER GAUGE—BELOW OLD FORT ISLAND

A staff gauge was established by the Manitoba Hydrographic Survey in the pool of the Winnipeg River directly below Old Fort Island on October 8, 1914. Readings of this gauge were taken daily from its establishment up to December 4, 1914, when the station was discontinued for the winter.

The readings of the gauge together with the gauge zero appear in Table 24 and the readings are shown graphically on Plate 67.

WINNIPEG RIVER GAUGE—MINAKI, ONTARIO

In September, 1913, a staff gauge was established by the Manitoba Hydrographic Survey at Minaki, Ontario, near the east end of the National Transcontinental Railway bridge. Readings of this gauge are available from September 24, 1913, to December 5, 1914, and from May 18 to December 31, 1915.

These readings appear in Table 23 and are shown graphically on Plates 66 to 67A.

OBSERVED WATER LEVELS—LAKE OF THE WOODS

SUMMARY OF AVAILABLE RECORDS

The following records of lake stages, and records of water levels in the various head races or canals leading from the Lake to the turbines of mills and power plants, are available for certain years between 1892 and 1914:

	Table.	Plates.
1. Records of Mr. James C. Kennedy, Engineer for the Keewatin Power Company: Lake levels observed at Norman, Ontario, from October, 1892, to October, 1895, and from July to December, 1898	6	39, 40, 42
2. Records of the Department of Public Works, Ontario: Lake levels observed at Norman, Ontario, from November, 1899, to November, 1905, and at Keewatin, Ontario, from November, 1905, to date	7	42 to 50
3. Records of the United States War Department: Lake levels observed at Warroad, Minnesota, from May, 1899, to January, 1900; May to September, 1903; March to October, 1904; and practically continuously from April, 1905, to date	8	42 to 50
4. Records of the Lake of the Woods Milling Company: Fore bay levels at Mill "A," at Keewatin, Ontario, observed several times a month during most of the period from 1896 to 1912	9	41 to 49
5. Records of Kenora Municipal Power Plant: Fore bay levels observed at Kenora, Ontario, from August, 1907, to date	10	46 to 50
6. Records of Ontario Hydro-Electric Power Commission: Lake levels observed at Kenora, Ontario, from October, 1905 to May, 1906	11	45, 46
7. Records of Mr. George Drewry: Lake levels observed at his boathouse at Kenora, Ontario, on occasional calm days between 1908 and 1912	13	47 to 49
8. Records of Mr. Wm. Lyon: Fore bay levels observed at the headworks of the Keewatin Lumber and Manufacturing Company's Plant, at Keewatin, Ontario, on occasional days between 1898 and 1902, and again between 1904 and 1906	12	42 to 46
9. Record of A. Pringle: Fore bay level above old Kenora Municipal Power Plant taken during discharge measurement on July 29, 1903	.....	44
10. Records of Mr. G. M. Wynn: Fore bay levels observed above the site of the old Kenora Municipal Power Plant during the construction of the present plant, on occasional days from June to October, 1906	20	46
11. Records of Manitoba Hydrographic Survey, Water Power Branch, Canada: Lake levels observed at the Keewatin Lake Bridge, Keewatin, Ontario, from June, 1913, to date	14	49, 50
12. Records of the International Boundary Commission, and the International Joint Commission: Lake levels observed at Warroad, Oak Island, and Oak Point, Minnesota, during the summer seasons of 1912, 1913, and 1914	15 to 19	48, 49

CORRELATION OF DATUMS

The records of observed water levels on the Lake of the Woods express stages in relation to various datums. In order that these records might be readily compared, it was necessary to make a correlation of the datums used and to reduce all of the gauge readings to one common datum. For this purpose, the United States Coast and Geodetic Survey and the United States Geological Survey sea-level datum, 1912 adjustment, at Warroad, Minnesota, is used.

The United States Coast and Geodetic Survey carried its lines of precise levels to Stephen, Minnesota, about 100 miles southwest from the southerly shore of the Lake of the Woods. From the Geodetic Survey's bench mark at Crookston, Minnesota, on the line to Stephen, the United States Geological Survey carried precise

levels to Warroad, Minnesota, on the southwestern shore of the Lake. In order that full assurance may be felt toward the elevations of bench marks in Warroad, Minnesota, as determined by the United States Geological Survey, it may be well to quote Mr. R. B. Marshall, Chief Geographer of the Geological Survey, as follows:

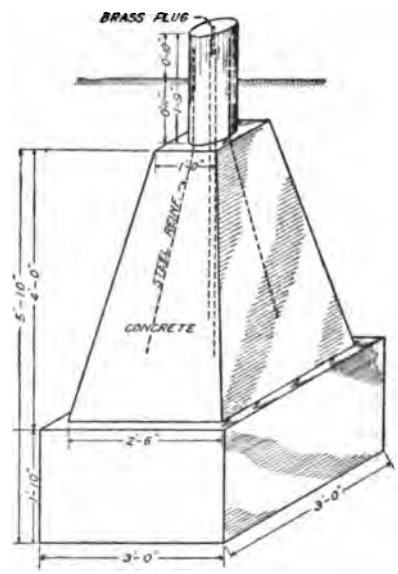
"Instruments and rods of the highest grade were used. The allowable divergence between the forward and backward lines in feet is represented by the formula, $0.017\sqrt{D}$, in which D is the distance in miles between bench marks."

As the precise levels which have been carried to Keewatin, Ontario, and to Warroad, Minnesota, by the Canadian Geodetic Survey, are based upon the United States Coast and Geodetic Survey elevations at Stephen, Minnesota, we have concluded to adopt as sea-level datum, for the purpose of this investigation, the datum used by the United States Coast and Geodetic Survey, and the United States Geological Survey, in their 1912 adjusted elevations of the United States Engineer Bench Mark No. 303 at Warroad, Minnesota. The Canadian levels check those of the United States at Warroad, to within plus 0.18 ft.; and also check the United States sea-level datum, at Keewatin, Ontario, transferred by us, by water levels, from Warroad to within minus 0.02 ft.

At the time the United States Geological Survey carried its levels into Warroad in July, 1907, the party established a pipe bench mark in the school grounds of that town, and fortunately, also, determined the elevation of the tile and pipe Bench Mark No. 303, in Mr. Moody's yard, established by engineers of the United States War Department in 1899. All engineers who have used these two bench marks agree that the Army Engineer's bench mark is the more permanent of the two,—that of the Geological Survey gives evidence of having been disturbed because the top is more or less battered, apparently from pounding with rocks; and besides, the bench mark appears to have been subjected to some heaving by frost. We have, therefore, accepted the 1912 adjusted elevation of the United States Army Engineer Bench Mark No. 303, as furnished us through the United States Coast and Geodetic Survey, and the United States Geological Survey, and have endeavored to fix the datum which we have adopted, still more permanently, through the construction of a massive concrete bench mark on the school grounds at Warroad, details of this bench mark are shown in the accompanying sketch. Precise levels were carried by the Canadian Geodetic Survey between Bench Mark No. 303 and the concrete bench mark, which will hereafter be referred to as the International Joint Commission Bench Mark at Warroad.

Having adopted a sea-level datum at Warroad, Minnesota, it was desirable to transfer this datum across the Lake, so that all gauge readings on the Lake of the Woods might be reduced to this

datum. Immediately after the Hearings held in October, 1912, a preliminary transfer of sea-level datum was made by means of half-hourly gauge readings taken at the various Lake of the Woods gauges, and extending over a period of thirteen consecutive days. A more refined transfer of sea-level datum from Warroad to Kenora, and other points on the Lake of the Woods, was made while the Lake was covered with ice, on March 12th, 13th, and 14th, 1914. By means of hook gauges, hourly readings of water levels were made day and night from 9 a. m., March 12th to 6 p. m., March 14th. Temperature, barometric pressure, wind and weather conditions were also observed. The essential data pertaining to both the 1912 and the 1914 transfers of sea-level datum are shown on Plates 16, 17, and 18.



International Joint Commission Permanent Bench Mark at Warroad, Minnesota.

The readings of the hook gauge, at Warroad, Minnesota, during the transfer of sea-level datum, were tied in directly to the International Joint Commission's permanent bench mark, previously described. It is interesting to note that the average difference between sea-level datum at Warroad and the local datum at Keewatin, as determined from the average open water readings of the three calm days chosen out of the thirteen days over which readings extended, during October, 1912, agrees within less than .01 foot of the final determination made by the more refined methods of March, 1914. The transfer of elevations by water levels, whenever large bodies of water are available, is common practice on Government surveys, and under the methods adopted by us the results are perfectly reliable.

The effect of wind on the readings of the various Lake of the Woods gauges is well exemplified by the half-hourly readings taken during the preliminary correlation of October, 1912, shown graphically on Plate 16. Wind effect must frequently be taken into consideration in the determination of mean lake levels, particularly when the available gauge readings have all been taken at the same end of the Lake. It is interesting to note that, at 1:30 p. m. on Oct. 7, 1912, the Lake was .82 foot lower at Warroad, Minnesota, than at Keewatin, Ontario; and two days later, as the result of brisk southwest winds shifting to northeast winds, it was .80 foot higher. It is also

interesting to note that on October 18, 1912, the lake rose 1.04 feet in six hours at Oak Point, near the mouth of the Rainy River, as the result of a gale from the northwest. Evidently, changes in lake stages of a foot or more, following a shift in the wind, are very common occurrences on the Lake of the Woods—as on other lakes, more especially the shallower ones—and these changes must be taken into consideration, not only in deriving mean lake levels from observed gauge readings, but also in weighing the effects, on the various interests involved, of any proposed regulation of levels.

LOCAL GAUGE READINGS EQUIVALENT TO VARIOUS SEA-LEVEL ELEVATIONS—LAKE OF THE WOODS

Sea-level Elevation 1912 Adjustment	Local Gauge Readings During Specified Periods					Water Power Survey Datum
	Warroad Lake Gauge		Kennedy Lake Gauge Norman	Public Works, Ontario, Lake Gauge **Norman and Keewatin		
	*1899–1911 and Apr. 1 1914, to date.	June 1, 1912, to Mar 31, 1914	Oct., 1892, to Dec., 1898	Nov. 19, 1898, to Oct. 31, 1905	Dec. 1, 1905, to date	
A	B	C	D	D¹	E	F
1054	0.4	−0.6	94.0	94.0	92.9	1052.7
1055	1.4	0.4	95.0	95.0	93.9	1053.7
1056	2.4	1.4	96.0	96.0	94.9	1054.7
1057	3.4	2.4	97.0	97.0	95.9	1055.7
1058	4.4	3.4	98.0	98.0	96.9	1056.7
1059	5.4	4.4	99.0	99.0	97.9	1057.7
1060	6.4	5.4	100.0	100.0	98.9	1058.7
1061	7.4	6.4	101.0	101.0	99.9	1059.7
1062	8.4	7.4	102.0	102.0	100.9	1060.7
1063	9.4	8.4	103.0	103.0	101.9	1061.7
1064	10.4	9.4	104.0	104.0	102.9	1062.7

*Since 1899 the United States War Department has maintained a gauge at Warroad, now known as the "Old U. S. Engineer Gauge." This gauge is still attached to the old dock and consists of a board, with its graduations marked by means of brass tacks. The dock to which the gauge is attached shows unmistakable signs of having been heaved by frost, and the original gauge zero of 1053.6 does not apply after November 30, 1911.

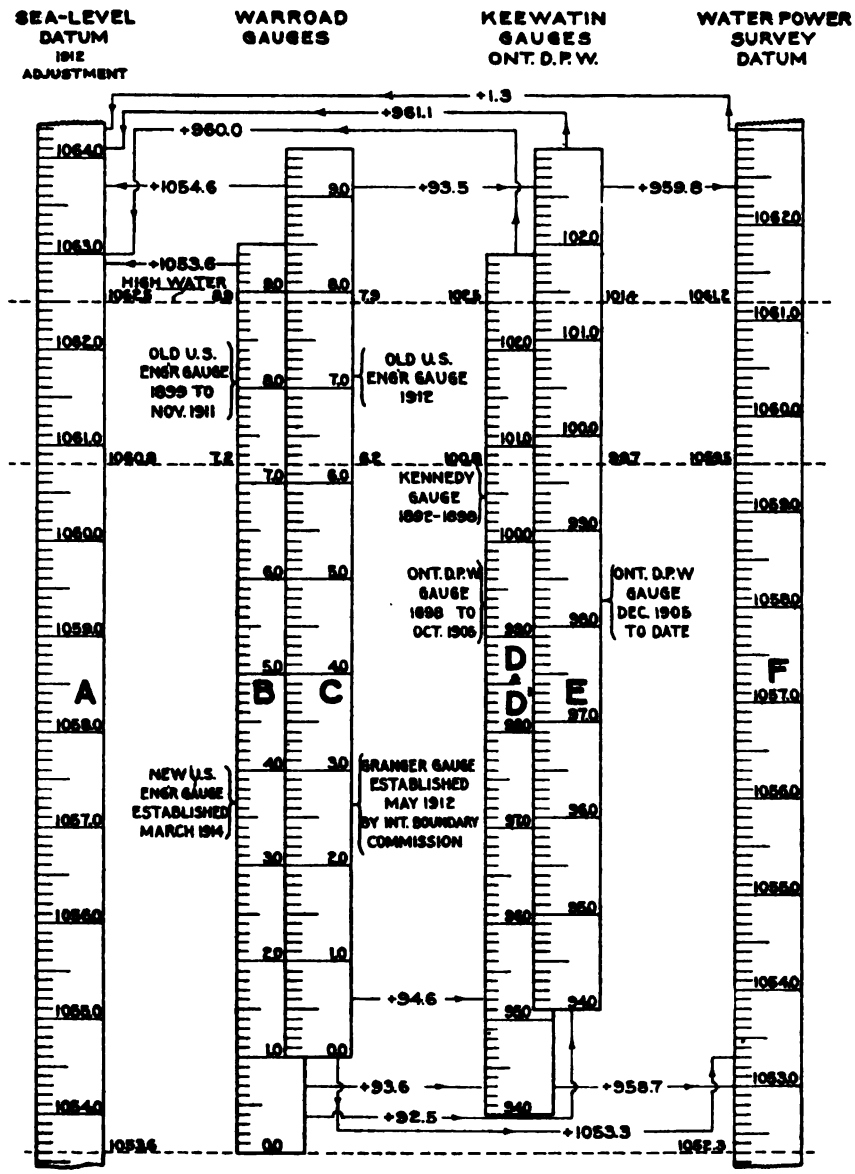
¹The International Boundary Commission, in May, 1912, established a gauge at Warroad, known as the "Granger Gauge." The Canadian Geodetic Survey, in July, 1913, determined the zero of this gauge to be 1054.60.

In March, 1914, the International Joint Commission, coöperating with the United States War Department, established a new gauge at Warroad, known as the "New U. S. Engineer Gauge," with its zero at substantially the same datum as the "Old U. S. Engineer Gauge."

**The Public Works, Ontario, lake gauge was located at Norman from November 19, 1898, to October 31, 1905, and at Keewatin from December 1, 1905, to date.

NOTE: For detailed checks of these gauges see chapter on "Observed Water Levels—Lake of the Woods."

CORRELATION OF GAUGES AND DATUMS LAKE OF THE WOODS



RECORDS OF JAMES C. KENNEDY AT NORMAN, ONTARIO

The earliest records of water levels on the Lake of the Woods which we have been able to secure are those taken by Mr. James C. Kennedy, formerly Resident Engineer for the Keewatin Power Company.

These records of Mr. Kennedy constitute the first recorded lake stages which were definitely referenced to a datum which has been preserved, and the elevation of which it has been possible to determine with reference to sea-level datum. Kennedy's gauge heights were all referred to what is known as the "100" datum at Keewatin and Kenora. This datum has been preserved by a bench mark on one of the piers of the Norman Dam, and by certain marks cut on rocks in various portions of the Lake of the Woods.

According to a statement made by Mr. Kennedy, his information regarding this "100" datum came from Mr. T. Turnbull.*

Mr. Turnbull, in December, 1891, made some preliminary surveys for the Keewatin Power Company. On this occasion he selected a datum 100 feet below the surface of the Lake of the Woods as he then found it. Mr. Turnbull has stated "I started my levels, taking the surface of the ice in the Lake of the Woods as elevation '100'". He cut a crow's foot in the rock shore of the Western Outlet at this assumed elevation.

Mr. Kennedy has stated that when he arrived at the Lake of the Woods, he learned of the existence of, and subsequently found, Turnbull's 100 Bench Mark. It was cut on a sloping rock near the down-stream side of the westerly end of the old Rollerway Dam.

Mr. William Kennedy (a brother of James C. Kennedy), has furnished the following memorandum from his note book, which, he says, is information supplied, at the time, by Mr. Turnbull respecting his bench mark.

> North side of road near W. end of highway bridge elevation 100.00 B. M. ↑ cut on rock on shore say 20–30 feet down stream from bridge.

In establishing his vertical staff gauge on a portion of the old Rollerway Dam, Kennedy assumed Turnbull's crow-foot mark as at elevation 100, and leveled across from this mark, placing the 100-foot mark of his gauge on the same level as the crow-foot bench mark.

A plotted record of the early gauge heights taken by Kennedy and his assistants is in Mr. A. V. White's possession, and a cut of a portion of one of the charts is shown on Plate R. The earliest recorded lake stage on these charts is a single record of †98.18 on July 15th, 1889, and another record of ‡99.38 on July 15th, 1890. From

*Mr. Turnbull was associated with some of the earlier engineering activities connected with the location and construction of the Canadian Pacific Railway. Compare *infra*, p. 171.

†1058.18 sea-level datum. ‡1059.38 sea-level datum.

November, 1892, to October, 1895, the records are practically continuous, and are plotted on two charts,—the actual gauge readings, in figures, having frequently been recorded on these charts in pencil figures.

On April 16th, 1913, Mr. Kennedy identified the charts and inscribed upon each of the two sheets of gauge records covering the gauge heights on the Lake of the Woods from 1892 to 1895, and part of 1898, the following note:

MONTREAL, April 16, 1913.

This chart was submitted to me this day and I hereby identify the same as a record of the lower water-gauge readings taken by me and under my direction, during my term of office as Resident Engineer for the Keewatin Power Company, Limited.

The plottings were made from day to day as the readings were obtained—this is the original sheet.

(Sgd.) JAMES C. KENNEDY.

Witnesses:
(Sgd.) ARTHUR V. WHITE.
(Sgd.) WILLIAM KENNEDY, Jr.

Besides these two larger charts, there is a small chart bearing James C. Kennedy's signature, which shows readings of the lake and other gauges during December, 1894, and January, 1895. These charts have all been photographed and copies placed on record in the Offices of the International Joint Commission.

In addition to the records of lake stage shown on the above mentioned charts, we have been furnished, by Mr. S. S. Scovil, of the Water Power Branch, Department of the Interior, Canada, with tabular records of lake stages from January to October, 1895, and for parts of July, August, September, October, November, and December, 1898. These records were taken directly from the field notes and records of Mr. Kennedy.

Although Turnbull's crow foot, in spite of diligent search, has not yet been found, and may have disappeared through the breaking down of rocks along the shore of the Lake, certain marks consisting of the letters "HW," cut into rocks at various points on the Lake of the Woods under Mr. Kennedy's direction, in 1895, and discussed in detail later in this report, have all been located, and their elevation determined with reference to sea-level datum. As the elevation of Kennedy's high water mark on Tunnel Island, in Rat Portage Bay, is known in terms of both the "100" datum and sea-level datum, it has been possible to reduce the readings of Kennedy's gauges to sea-level datum.

In addition, it has been possible to determine the relation between Kennedy's "100" datum and sea-level by determining the elevation of the bench mark, (elevation 104.37) of the Keewatin Power Co., chiseled on the top of the fishway abutment of the Norman Dam. This is a bench mark used by Mr. Kennedy during the con-

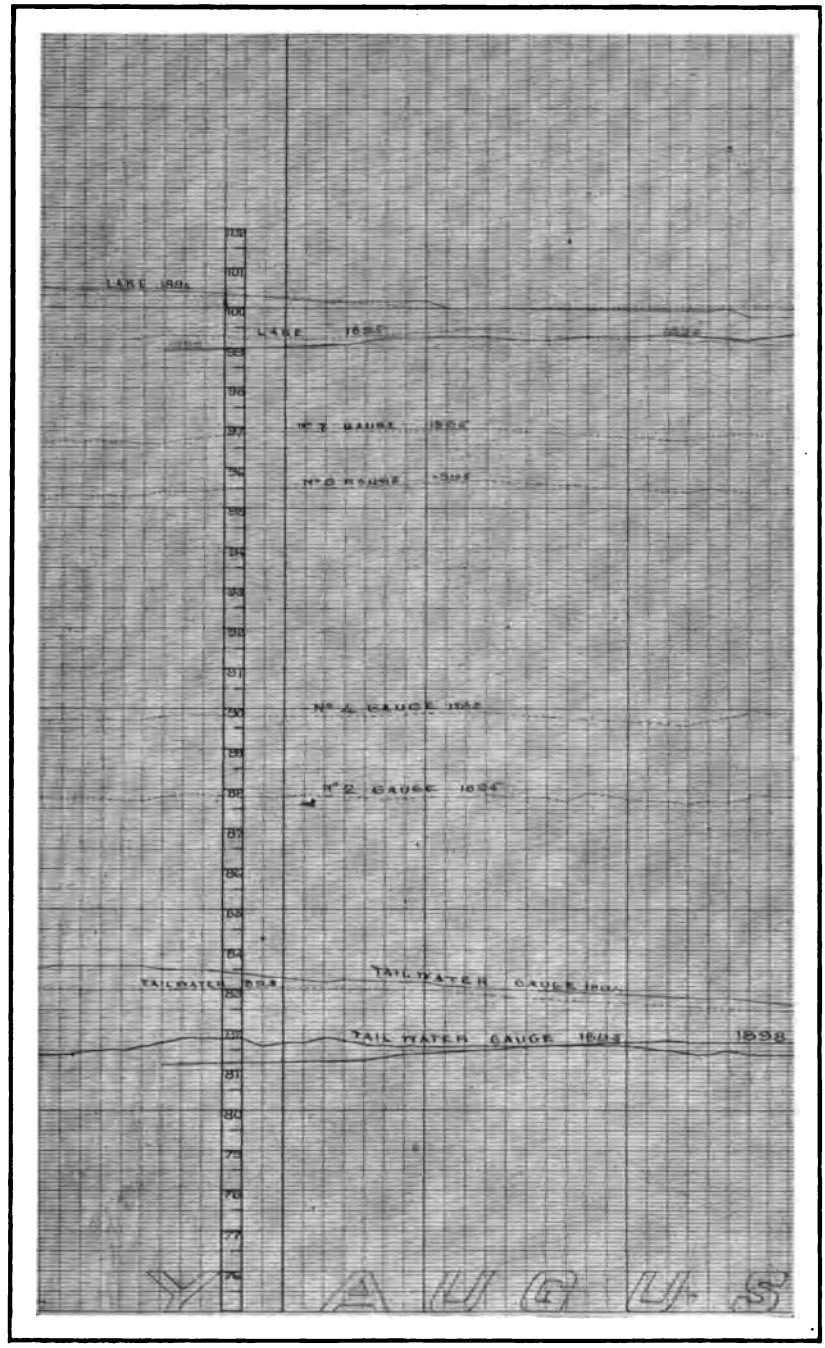
PLATE Q

1 & 2. TYPICAL INTERNATIONAL JOINT COMMISSION TEMPORARY BENCH MARKS ON ROOTS OF TREES

3. "500" BENCH MARK OF DEPARTMENT OF PUBLIC WORKS, CANADA, AT FORT FRANCES

4. KENNEDY'S BENCH MARK (104.37) ON PIER OF NORMAN DAM

PLATE R



PORTION OF KENNEDY CHART

struction of the dam. In a note book of Mr. Wm. Kennedy under date of Monday, 3/10/92, reference is made to a Bench Mark as follows:

N E corner coping stone, E abutment C. P. Railway Bridge for west branch Winnipeg River, Bridge 113. Elevation 127.99.

The determination of the relationship between Kennedy's "100" datum and sea-level datum may be summarized as follows:

	Elevation		Equation Kennedy to Sea Level
	Kennedy Datum	Sea-level Datum	
Kennedy high water mark, Rat Portage Bay	*102.54	1062.58	960.04
Kennedy B. M. 104.37 Top of pier, Norman Dam	104.37	1064.35	959.98
N. E. corner coping stone, E. abutment, Bridge 113	127.99	1087.89	959.90

An average value of 960.0 has been used in reducing the Kennedy gauge heights to sea-level datum.

*Under date of March 10th, 1913, Mr. Kennedy wrote respecting the establishment of these water marks as follows:

"I have a distinct recollection of adopting certain bench marks previously established by Mr. Turnbull, C. E., in making surveys for the Keewatin Power Co., and of adhering to his datum level throughout my service with the same Company as Resident Engineer in charge of the construction of the 'Keewatin Dam.' Normal high water of the Lake was 100 feet above datum.

"I have a further distinct recollection of tieing in with my adopted datum the elevation of the HW mark cut in the rock in Rat Portage Bay near the C. P. Railway in order to make a relative record and which record will show HW mark at the location just described to be 102.54 feet above that datum."

RECORDS OF THE DEPARTMENT OF PUBLIC WORKS, ONTARIO, AT NORMAN AND KEEWATIN, ONTARIO

The Kennedy records, previously discussed, were taken during the construction of the Norman Dam on the western outlet of the Lake by the Keewatin Power Co. It appears from certain notes that in November, 1898, the operation of the Norman Dam was turned over by this company, to representatives of the Ontario Government, Alexander McQuarrie, of Norman, Ont., being placed in charge. James C. Kennedy, however, continued to take certain readings of gauges at the Norman Dam until the 9th of December, 1898.

On October 14th, 1898, Mr. Kennedy placed a gauge, known as the "Above Dam" gauge, on the southeast corner of the fishway, and another, known as the "Tail Water" gauge, at the lower end of the fishway. During the latter part of November, Kennedy evidently checked the various water gauges, although no record has been found indicating the exact instrumental checks secured. Evidently Mr. McQuarrie received instructions for reading the various gauges from Mr. Kennedy.

Mr. McQuarrie has stated that the first gauge he read was pointed out to him by one of the Mr. Kennedys associated with the construction of the Norman Dam, and that this gauge, from time to time, was checked by Mr. Kennedy to make sure that it was correct. Mr. McQuarrie says, further, that after the old Rollerway Dam, and substructure of the old Highway Bridge were removed, by dynamite, a gauge was established on an old log said to have been firmly embedded

in the westerly shore, and near the end of the old Rollerway Dam. This gauge was set by one of the Mr. Kennedys to the same datum as the first gauge read by Mr. McQuarrie.

Mr. McQuarrie also had a gauge, fastened to a stake in the Lake, near his house. It was located on the lakeward side near the boom which ran from McMillan's Island to the shore near his house. He says, however, that this gauge near his house was not very stable, and as there was no occasion to read it, his house being located very near to the gauge at the old Rollerway Dam, he did not bother much about reading this gauge.

Lake stages were evidently read on the gauge at the site of the Rollerway by McQuarrie until August 1st, 1903, by Lemay from August 1st, 1903, to April, 1905, and by Hansen from April, 1905, until November, 1905, when the gauge was moved to the old Keewatin bridge, about two miles west of the location of the original Kennedy gauge.

No definite record was made of the change of the lake gauge from Norman to Keewatin. The following notes, accompanying the gauge readings, however, are of interest in this connection.

> July 21–31, 1905. Have taken out 130 logs up to date. Dock at Norman floating. The lake is higher than what I have got on the report. It has lowered five inches according to gauge put on a week ago but stays same on dock.
>
> September. Water has dropped five inches I haven't found McQuarrie's gauge at his house I put in 101 mark I haven't measured down to it and it now stands one foot over it. I think it's right 102. I will be able to tell when the water gets down lower.
>
> September. Put in fifty logs on the 21st, 22nd, 23rd, as you can see by the report it lowered tailwater. Water stands on the same level at Norman.

The 101 mark to which the gauge reader (Hansen) refers was apparently at the correct elevation, as the water level, 102, agrees with the observed level at Warroad between September 11th and 17th, 1905.

The Department of Public Works records for October, 1905, when reduced to sea-level datum by using the zero of 960.0, check the Warroad records for this month. The wind effect of the severe storm of October 1st is very apparent in both the Norman and the Warroad gauge readings.

On November 30th, December 16th, and December 30th, 1905, the Warroad gauge indicated lake levels of 1061.6, 1061.7, and 1061.6, respectively. This gauge was checked and found correct on December 16th, 1905, consequently, these levels may be considered correct to the nearest tenth. The Ontario Hydro-Electric Power Commission's records of lake levels at Kenora,* give a lake elevation for

* These readings are not referred to existing bench marks but have been reduced to sea-level datum by the addition of 457.2 on the basis of the average relationship between the Ontario Hydro-Electric Power Commission and the Warroad gauges during the period for which both records are available.

December, 1905, of approximately 1061.6. The Department of Public Works records for December, 1905, give 100.60, which, when reduced by the addition of 960.0—the constant previously used in reducing these gauge heights—gives 1060.60 as the lake elevation, or a difference of 1 foot.

This difference, occuring during the month of November, coupled with the fact that the Lake gauge is known to have been moved to Keewatin at about this time, warrants the inference that when making the transfer of the gauge from Norman to a pile at the southerly end of the old Keewatin Traffic Bridge a mistake was made of approximately 1 foot.

In 1906, according to information supplied by the Manitoba Hydrographic Survey, the gauge was again transferred by water level from the old Keewatin bridge to the present bridge, which had been built some 20 feet east of the old one. Builders of the new bridge have stated that the piles at the southerly end, where the gauge is located, are driven to rock bottom. They are of the same opinion with reference to the piles at the southerly end of the old bridge. It is probable, then, that the zero of the Keewatin gauge has remained practically constant since 1905. Up to the end of October, 1905, the constant of reduction is taken as 960.0. The month of November is neglected. Beginning December 1, 1905, the constant is changed to 961.1.

No records exist of instrumental checks having been made of the various gauges used by the gauge readers of the Department of Public Works, Ontario, between 1905 and 1911, when the present Keewatin lake gauge was tied in to a permanent bench mark by the Manitoba Hydrographic Survey, in connection with the Winnipeg River Power surveys. Since that date, however, frequent checks have been had on the zero of this gauge, as given in the following table:

Determination of zero, Department of Public Works, Ontario, Lake gauge, Keewatin, Ontario.

	Zero elevation sea-level datum.
Sept. 22, 1911	961.16
June 22, 1912	961.115
Oct. 12 & 19, 1912	961.115
Mar. 5 & 13, 1913	961.075
July 30, 1913	961.065
Dec. 8, 1913	961.07
Mar. 31, 1914	961.07
April 14, 1914	961.07
June 1, 1914	961.08
July 8, 1914	961.075
Sept. 14, 1914	961.07
Dec. 11, 1914	961.07

A photograph of the present Public Works lake gauge at Keewatin is shown on Plate S. A zero of 961.1 has been used in reducing the readings of the gauge between December 1st, 1905, and April 30, 1912, to sea-level datum. Since May 1st, 1912, the zero given by the instrumental checks has been used in reducing the gauge readings to sea-level datum.

Two sets of records of the readings of the various gauges used by the gauge readers of the Department of Public Works, Ontario, between 1898 and 1914, are available. One set of records consists of bound Record Books, and the other consists of sheets, apparently copied from the Record Books, and transmitted to the Toronto Office of the Department of Public Works, Ontario, at irregular intervals of from one to two weeks. In answering some inquiry about his records, on July 17, 1899, for example, the gauge reader remarked, "I had it in my book all right." A careful examination of these two sets of records supplemented by special inquiry has convinced us that the gauge readings were not recorded either in the Record Books or on the Sheets as taken from day to day. It has been stated that the readings were copied into the Book from time to time, from a memorandum made by the readers when making their rounds of the gauges.

On the whole, the Record Books can unquestionably be given greater weight than the Sheets filed at Toronto. In these Record Books there were recorded the readings of the gauges in the Lake, at the upper end of the fishway in the Norman Dam, and at the lower end of the fishway. In places, as for example, from August 5th to 16th, 1900, the records on the Sheets indicate that entire columns of figures were misplaced in transferring them from the Record Books to the Sheets. In other places there is some question as to whether certain readings were intended to be recorded as .5 or .05. Readings were not always recorded in the same way, as for example, what is apparently intended for 93.00 appears in various places as 93=, 93, 93., 93−, and 93′′′′, and what was evidently intended for 93.05 appears as 93.5, 93.−5, 93. 5, and 93′′5.

In addition to the less important discrepancies in gauge records just referred to, there are unmistakable indications of unreliability in the records of Napoleon Lemay, who acted as gauge reader between August 1st, 1903, and April, 1905. For example, the readings appearing in the Record Book from February 16th to 29th, 1904, for all gauges, are the same as those which appear on the previous page for February 1st to 14th of the same year. Readings of all gauges between July 16th and 30th, 1904, are exactly the same as the readings for July 1st to 15th of the same year. No record, whatever, appears for July 31st of that year. Corresponding indications of unreliability appear in the records of December, 1904, and January, 1905.

PLATE S

1. UNITED STATES GEOLOGICAL SURVEY AND DEPARTMENT OF PUBLIC WORKS, CANADA, AUTOMATIC AND STAFF GAUGES ON DOCK AT INTERNATIONAL FALLS
2. UPPER PULP MILL GAUGE—INTERNATIONAL FALLS
3. DEPARTMENT OF PUBLIC WORKS, ONTARIO. GAUGE ON KEEWATIN LAKE BRIDGE
4. GRANGER GAUGE AT WARROAD
5. INTERNATIONAL JOINT COMMISSION GAUGE AT OAK POINT—LAKE OF THE WOODS
6. KENORA MUNICIPAL PLANT FOREBAY GAUGE
7. GRANGER GAUGE AT OAK ISLAND

RECORDS OF UNITED STATES WAR DEPARTMENT AT WARROAD, MINNESOTA

The Warroad gauge was established May 18, 1899, by T. Milton Fowble, detailed from the U. S. Engineer Office at St. Paul, Minnesota. The gauge consisted of a graduated 2″×4″ stud spiked to the outer and easterly piling of Mr. Moody's dock. The zero of the gauge was placed at 1000 according to an assumed datum. At the same time, a temporary bench mark was established, consisting of a spike driven into the northwesterly side of a burr oak tree 8″ in diameter, about 40 feet westerly from Mr. Moody's house. The elevation of this B. M. was 1014, according to the assumed datum.

In 1900, a permanent bench mark was established by Mr. C. W. Raynor, also of the U. S. Engineer Office. This bench mark consists of a tile, with a copper bolt in the center of it, buried about 3½ feet below the surface of the ground, and a cast iron pipe 3″ in diameter and 4′ long, set over the bolt in the tile and projecting about 9″ above the ground. A cast iron cap, elevation 1012.35 according to the assumed datum, lettered U.S.E.B.M. 303, secured to the top of the pipe with two brass screws, constitutes the temporary bench mark. The copper bolt, elevation 1008.45, according to the same assumed datum, constitutes the permanent bench mark. The elevation of all these bench marks, as previously stated, have now been ascertained in terms of sea-level datum.

The gauge established by Mr. Fowble was read during the season of 1899. From the close of that year until May 15, 1903, except for three records during January, 1900, apparently no readings were taken. From May 15, 1903, until the present time, the gauge heights have been observed daily except during the winter months of a few years.

A summary of the checks of the zero of the Warroad gauge, established in 1899 with its zero at elevation 1053.61 sea-level datum, is given in the following table:

Determination of Zero, United States Engineer Gauge, Warroad, Minnesota

Mar. 11/04. R. Davenport. United States Engineer Office. Correct to .01 ft.	
Dec. 16/05. Horace Dunaway. United States Engineer Office. Correct to .05 ft.	
Sept. 25/06. E. J. Dugan and R. Davenport. United States Engineer Office. Correct. New gauge placed.	
July 10/07. United States Geological Survey. Correct to .1 ft.	
May 19/12. F. D. Granger. International Boundary Commission. Old Engineer Gauge	1054.58
May 19/12. F. D. Granger. International Boundary Commission. Granger Gauge	1054.612
Oct. 1/12. S. B. Soulé. International Joint Commission. Old Engineer Gauge	1054.60
Oct. 1/12. S. B. Soulé. International Joint Commission. *Granger Gauge	1054.622

Mar. 13/13. Alex. Pirie. Manitoba Hydrographic Survey. Granger Gauge..... 1054.586
July/13. D. McMillan. Canadian Geodetic Survey. Granger Gauge. 1054.595
Mar. 20/14. H. I. Merricks. International Joint Commission. New Engineer Gauge..... 1053.606
Oct. 13/14. Geo. M. Garen. International Joint Commission. New Engineer Gauge..... 1053.58
May 22/16. George M. Shepard. International Joint Commission. New Engineer Gauge..... 1053.57

The dock in Warroad Harbor, to which the U. S. Engineer gauge was fastened, shows, at present, unmistakable evidences of having been heaved by frost. When the zero of the old gauge was determined by the late Mr. F. D. Granger in May, 1912, it was found to be practically a foot higher than when last checked. This change of zero may have been gradual. A comparison of the Warroad gauge records with the Keewatin records indicates that the change began in January, 1911.

Except for short periods when they were taken at Warroad, the gauge heights, from July 19, 1911, to July 23, 1912, were taken at Zippel, on the south shore of the Lake, about 28 miles, by water, easterly from Warroad. The indications are that both gauges were unstable during this period. On account of the uncertainty respecting the gauge zero during this period, the Warroad records have not been given much weight and have not been platted on the graphs from December 1, 1911, to April 27, 1912.

In May, 1912, a new gauge was fastened to the upper end of the Warroad dock by the late Mr. F. D. Granger, of the International Boundary Commission's field staff. This gauge was set to practically the same zero as the old U. S. Engineer gauge. The zero, as determined by Mr. Granger at the time he established his gauge, was 1054.61 sea-level datum.

In March, 1914, a new gauge, furnished by the U. S. Engineer Office, was fastened to one of the pile bents of the Canadian Northern Railway Bridge by the Engineers of the International Joint Commission, with its zero at the same elevation as the original U. S. Engineer gauge, namely 1053.61.

From the first records taken in 1899, to November 30, 1911, a zero of 1053.6 has been used in reducing gauge heights to sea-level datum. A comparison of the readings of the Warroad and the Zippel gauges from June 1, 1912, to July 22, 1912, gives a zero of 1054.05 for the Zippel gauge. This zero was used from April 28 to July 22, 1912, after which readings were again taken at Warroad, Minnesota, by the gauge readers of the U. S. Engineer Office. From July 23, 1912, to March 31, 1914, readings were taken on the Granger gauge at Warroad. These records have been reduced to sea-level datum by

* The elevation of cap of U.S.E.B.M. 303 was found correct relative to the elevation of the tile.

adding 1054.6. From April 1, 1914, to Dec. 31, 1914, the gauge zeros determined by the instrumental checks, as given in the preceding table, have been used in reducing readings to sea-level datum.

RECORDS OF LAKE OF THE WOODS MILLING COMPANY AT KEEWATIN, ONTARIO

Between 1896 and 1912, frequent determinations were made of the elevation of the water level in the turbine pits of the Lake of the Woods Milling Company's Mill "A" at Keewatin, Ontario. The method of obtaining these records consisted of measuring down to the water surface, through a hole in the floor of the power house, with a graduated stick. The distance between the top of the floor and the surface of the water in the turbine pit was recorded in feet and inches. The elevation of the floor of the mill at the point of measurement was found, by the Manitoba Hydrographic Survey, in 1912, to be 1064.31 sea-level datum, and it is understood that this same elevation holds for observations made prior to 1912. This floor was torn up during the latter part of 1912, when certain alterations were made at the mill.

In approaching the turbines of Mill "A," the water flows through a canal about 800 feet long, so that when the mill is running, the water level recorded in the turbine pit is always somewhat lower than that in the Lake, depending upon the fall in the canal or headrace and through the racks. In September, 1912, when the elevation of the floor of the mill was determined by the Manitoba Hydrographic Survey, there was a fall of 1.12 feet between the lake level and the water level in the turbine pits, where gauge readings were being taken. On days when the mill was shut down, however, the readings in the turbine pit would necessarily represent lake level.

The Mill "A" records are consistent throughout, and inspire confidence in their reliability. After making proper allowance for fall between the Lake and the Mill, these records may well be given considerable weight in arriving at mean lake levels during the period for which Mill "A" records are available.

RECORDS OF KENORA MUNICIPAL POWER PLANT AT KENORA, ONTARIO

Daily readings of the Kenora Municipal Power Plant fore bay gauge are available from August 21st, 1907, to date. It has been stated that, at first, the gauge was located on a timber structure on the easterly shore, about 40 feet above the screens of the power house, but that about two years afterwards it was moved down stream some 10 feet along this structure. No appreciable difference in zero elevation of gauge could reasonably have occurred in making this

change. The following checks on the zero of the present gauge have been made by the Manitoba Hydrographic Survey:

Determination of Zero, Kenora Municipal Power Plant Fore Bay Gauge, Kenora, Ontario

Sept. 21, 1911. Zero of gauge 692.65. Sea-level datum.
June 24, 1912. Zero of gauge 962.635. Sea-level datum.
March 3, 1913. Zero of gauge 962.675. Sea-level datum.
Sept. 28, 1913. Zero of gauge 1001.31. Sea-level datum. (Gauge datum changed.)

The fall from Lake to fore bay varies with the lake stage and discharge. For a high stage and average discharge the fall is .1 foot or less, increasing up to from .3 or .4 of a foot for a moderately low lake stage. Since these records are very accurate, they serve as a good check on the Keewatin lake records, and on Sundays or on other days of low discharge through the power plant the Kenora fore bay gauge practically records the lake level.

For all records previous to June 1, 1912, a gauge zero of 962.65 has been used. For subsequent records the gauge zeros determined by the instrumental checks, above, have been used.

It appears that "100" according to the old local datum used at the Kenora Plant corresponds, substantially, to Kennedy's high water mark on Tunnel Island, elevation 102.54 Kennedy's datum.

RECORDS OF THE ONTARIO HYDRO-ELECTRIC POWER COMMISSION AT KENORA, ONTARIO

Lake gauge readings made by the Ontario Hydro-Electric Power Commission's gauge readers at Kenora, from October 14th, 1905, to May 18th, 1906, are available. The gauge is stated to have been located slightly above the first power plant on the Eastern Outlet, but up to date no plan has been found showing the exact location. The gauge was established to an assumed datum, and Mr. H. G. Acres, Hydraulic Engineer of the Power Commission has stated that their bench mark was removed by blasting at the time of the construction of the present Kenora Municipal Plant. Even though the permanent bench mark to which this gauge was referenced has been lost, nevertheless the datum can be approximated quite closely by a comparison of these records with other available gauge readings. This has been done, and, when reduced by the addition of 457.20, the readings in question agree with those at Warroad during the months of October, 1905, and April, 1906. During the winter of 1905 to 1906 the readings are slightly lower than those at Warroad, as might be expected on account of the fall through the Devil's Gap.

The gauge readings of the Ontario Hydro-Electric Power Commission supply a continuous record of lake level at a time when the Keewatin readings are extremely unreliable.

RECORDS OF MR. GEORGE DREWRY, AT THE BOAT HOUSE AT KENORA, ONTARIO

Lake gauge records taken by Mr. George Drewry at his boat house, from 1908 to 1912, have been furnished us through the Manitoba Hydrographic Survey. A reading of five feet and three inches on Mr. Drewry's gauge corresponds to the level of the top of his boat house floor, giving a gauge zero, as determined by instrumental levels, of 1056.57 sea-level datum. It is understood that this floor is of permanent construction, and has remained at the present level during past years. Mr. Drewry has stated that once since 1900 there was 4 inches of water on the floor, giving a water level of 1062.15 at that time. Presumably this was in 1905, when the lake level at Warroad was recorded as 1062.15, and at Keewatin as 1062.00. Mr. Drewry stated that his records were taken only when the Lake was calm, and hence may be considered as thoroughly reliable.

RECORDS OF MR. WILLIAM LYON, OF THE KEEWATIN LUMBER AND MANUFACTURING COMPANY, AT KEEWATIN, ONTARIO

On April 20th, 1898, a graduated scale reading up to 6 feet was cut by Mr. William Lyon in the timber structure at the up stream side of the headworks of the old Keewatin Lumber and Manufacturing Company's plant, at the westerly end of Portage Bay, Keewatin. Mr. Lyon has stated that the water on this date was taken as the zero of the gauge, and that the scribe mark "W. L. 1898" was 6 feet above the water level of April 20th, 1898. The zero of Mr. Lyon's gauge, as determined by the Manitoba Hydrographic Survey, is 1057.02 sea-level datum.

Readings are available from 1898 to 1906, except for the year 1903, for which Mr. Lyon's records were lost. Although there is considerable fall through the head race from the Lake to this gauge, resulting in a level lower than that of the Lake, yet these records are of considerable value in indicating the trend of lake levels, and constitute a valuable check on other records.

RECORDS OF THE MANITOBA HYDROGRAPHIC SURVEY AT KEEWATIN, ONTARIO

Since June, 1913, readings of the Keewatin lake gauge of the Department of Public Works, Ontario, have been taken by gauge readers of the Manitoba Hydrographic Survey. These readings have been carefully made, the gauge has been frequently checked, and the records can be accepted with the fullest confidence.

RECORDS OF THE INTERNATIONAL BOUNDARY COMMISSION AND THE INTERNATIONAL JOINT COMMISSION

Readings of lake gauges were taken by gauge readers of the International Boundary Commission at Warroad from June 1 to October 31st, 1912, and from April 28 to October 31st, 1913; at Oak

Island from June 8 to October 31st, 1912, and from May 4th to October 27th, 1913; and at Oak Point near the mouth of Rainy River from July 28th to October 20th, 1913. During the summer of 1914, while the Lake of the Woods surveys were in progress on that portion of the Lake, the Oak Island and Oak Point gauges were read by gauge readers of the International Joint Commission.

The readings of these gauges have been taken with care, and can be accepted without reservation.

The Oak Island and Oak Point gauge readings, however, are omitted from the graphs of water levels because the mean lake level line for these years is so well defined by the records from the older stations, at Warroad, Keewatin, etc., that the addition of further points on the graphs would make most of them indistinguishable because of overlapping.

The greater accuracy and consistency of the records of the various lake gauges during the past three and one-half years, when the work of the gauge readers was subject to continual scrutiny, is forcibly brought to one's attention upon examining the graphs of observed water levels on the Lake of the Woods.

DETERMINATION OF MEAN OBSERVED LAKE LEVELS, LAKE OF THE WOODS

In view of the great discrepancies which have been found to exist between the lake levels recorded by some of the gauge readers on the Lake of the Woods at certain times in the past, it is believed desirable to present at least a few of the considerations which led to the adoption of the mean lake level line shown on the graphs of the observed water levels, Plates 39 to 50.

While outstanding differences characterize many of the gauge readings taken on the Lake during certain periods in the past, this comment does not apply to any of the Kennedy records. These records are consistent throughout, as may be seen by even a glance at the graphs, Plates 39, 40, and 42. Those "ear marks" of reliability, the daily fluctuations in stage, due to wind, are noticeable throughout these records. The mean lake level line for 1892 to 1895 simply follows the observed Kennedy readings. Daily wind effect has been eliminated as much as possible in order to derive a true mean stage.

From October 1895 to July 25th, 1898, no records of lake levels are available. Beginning with May 4th, 1896, however, we have the fore bay and tail water readings of the Lake of the Woods Milling Company at Mill "A." These fore bay levels, as previously stated, are lower than the level of the Lake itself by a variable amount, depending upon the stage of the Lake and the amount of water used by the Mill.

Notwithstanding this variable fall between Lake and head race at the Mill, these fore bay readings give a fairly good indication of

the lake stages which prevailed during these years. It is possible, however, to deduce quite accurate values for lake stages during the period from May, 1896, to July, 1898, from the tail water readings at Mill "A."

Simultaneous readings of the Norman Dam tail water and of the Keewatin tail water gauges during 1913 and 1914, indicate a fall between these two gauges, of about 0.1 foot at stages below 1041.5. The high water marks on the rock banks indicate a fall of a greater amount at higher stages. Consequently a fall of 0.2 foot has been used between water levels of 1042.5 and 1045, and of 0.3 foot for elevations above 1045.

By plotting the lake stages observed by Kennedy from 1892 to 1895 against tail water levels at the Norman Dam (reduced by the above mentioned values of fall between Norman and Keewatin so as to derive the equivalent tail water level at Keewatin) a curve showing the relation between lake stage and tail water level at Keewatin, Plate 107, was constructed. The upper portion of this curve is fixed, largely, by the high lake level of 1897, and the highest Mill "A" tail water level of the same year.

The available information, taken from the notes accompanying the gauge records, relating to the high lake level attained in 1897, is summarized below:

1. June 19, 1899, Lake Level 1061.50. NOTE BY GAUGE READER—"The water in the lake is still a foot below the high water mark of 1897."

2. June 26, 1899, Lake Level 1061.60. NOTE BY GAUGE READER—"Water in the Lake at a stand at present and about 10″ lower than the high water of 1897."

3. July 24, 1899, Lake Level 1062.30. NOTE BY GAUGE READER—"24th the water attained the height of 1897, but has gone down again."

4. "101.90 Kennedy's datum, or 1061.90 Sea-Level Datum, represents the H. W. of 1897 as indicated by a mark shown by Mr. Margach on his boat ho. at R. P. to J. C. Kennedy 19/8/98."

The above data indicate a high water level during 1897 of between 1061.9 and 1062.5. We believe that, for all practical purposes, a value of 1062.3 is sufficiently close to the truth.

The maximum tail water level given by the Mill "A" records in 1897 is 1046.1. This high level occurred during the latter part of July and at, practically, a constant stage.

We have, then, the two coördinates for the upper portion of our curve, namely, a lake stage of 1062.3, and a corresponding Keewatin tail water level of 1046.1.

On account of the discharge through the mills and power plants the outflow from the Lake cannot vary strictly as the lake stage—not even during these years of 1892 and 1895—while uniform control of discharge was being exercised at the Norman Dam. In view of the fact, however, that the flow through the mills is a very small per cent

of the total outflow from the Lake, the relation between lake stage and tail water level, for all practical purposes, does hold for these years.

It will be seen from an inspection of the curve of Plate 107, that none of the platted points vary a substantial amount from the mean as represented by the curve. The variation shown probably reflects both wind effect and the effect of discharge through the mills and power plants. In this connection it is well to note that during the months of July to November, 1898, the tail water levels, varying between 1038.0 and 1042.5, as observed by Kennedy at the Norman Dam, and the levels observed at Mill "A", substantiate, very well, the deductions previously made with respect to the relationship between the Norman and the Keewatin tail water readings.

To sum up,—the line of mean lake level from May, 1896, to August, 1898, has been computed from the Mill "A" tail water level, and checked approximately by the Mill "A" and William Lyon fore bay levels. The adopted line, it is believed, gives a substantially correct representation of mean lake stages prevailing during these three years for which no actual records of lake level are available.

For the period from October, 1895, to May, 1896, neither lake nor tail water readings are available. It has been possible, however, to make an approximate estimate for lake and tail water stages for this period by means of comparison with the changes in stage which occurred during the winters of 1892–1893, 1893–1894, and 1894–1895. Between October 10th, 1892, and the low water of April, 1893, there is a drop in the Keewatin tail water from 1044.20 to 1038.45. Between October 10th, 1893, and April 5th, 1894, there is a drop in the tail water from 1040.7 to 1035.6. Between October 10th, 1894, and March 30th, 1895, there is a drop in the tail water from 1040.4 to 1036.4. On October 10th, 1895, the mean tail water level at Keewatin is 1040.3 or within .1 of the tail water elevation of October 10th on the previous year, and within .4 of the tail water level on the second preceding October 10th. By comparison with the spring tail water reading of the previous year, a tail water level at Keewatin of 1036.0 on April 1st, 1896, would appear reasonable and close to the truth. A gradual drop in tail water is assumed to have occurred between October 10th, 1895, and April 1st, 1896, and the lake levels corresponding to these tail water elevations have been computed from the curve of relation of lake stage to tail water level at Keewatin, Plate 107, in the same manner as for the period from May, 1896, to August, 1898, when observed tail water levels at Mill "A" were available.

The following confirmatory checks on the lake levels as computed from tail water levels between September, 1895, and August, 1898, are available.

The note "High water mark in flume," dated July 29th, 1897, accompanies the Mill "A" fore bay readings. This date corresponds very well with that on which the highest computed lake level occurs.

The change in Mill "A" fore bay readings between October 28th and 29th, 1897, may be explained by the note dated October 29th, 1897, "Cleaned of front of rack."

On April 19th, 1898, the gauge reader noted, "Mill shut down." Under these conditions the fore bay gauge would practically record lake level. This being the case, the line of mean level is dropped slightly below the computed values, in order to pass through the observed fore bay level on April 19th, and a fall of approximately .5 foot used between lake and fore bay, during the remainder of the summer in accordance with the fall that obtains between August and November when both lake and fore bay levels are available. The William Lyon record of April 20th, 1898, substantiates the above conclusion.

From December, 1898, to September 1899, there is no difficulty in deciding upon the mean lake level. The records of William Lyon on November 18th, 1898, April 20th and July 14th, 1899, corroborate the other records.

The low Mill "A" and the Public Works lake records of September 28th, 1899, are explained by the following notes: from the Mill "A" records, "Strong north wind," and from the Department of Public Works records, "Gale from north 18 hours through midnight."

November 26th, 1899, occurs on Sunday, and consequently the fore bay gauge records give practically lake level.

From September 25th to the early portion of October, 1899, stop logs were placed in the Norman Dam, resulting in a drop in tail water from 1044.95 to 1038.5, corresponding to a reduction in discharge from 33,650 c. f. s. to 12,730 c. f. s. Previous to shutting off the dam, the Lake fell at the rate of .3 foot in 10 days, or equivalent to a draft of 14,375 c. f. s. from the Lake, giving a net runoff into the Lake of 19,275 c. f. s. Assuming a runoff of 19,275 c. f. s. beginning October 5th, the discharge corresponding to 12,730 c. f. s. from the Lake would result in a storage of 6,545 c. f. s., which in ten days would result in a rise in lake stage of .13 foot. As the runoff into the Lake would gradually decrease from September 25 on through the fall and winter, the Lake would gradually cease rising and then fall slowly. In accordance with these general propositions, the mean level is taken at practically 1061 from October 15th to December 1st, 1899, and assumed to drop gradually to meet the observed Warroad and Keewatin levels on December 20th to 27th.

A comparison of the Public Works records during the years 1900, 1901, and 1902 with the later records, at once impresses one with the peculiar variation in lake level shown by the earlier records These records do not manifest any well defined wind effects and yet,

at times, they show considerable fluctuation in lake level not readily accounted for by any physical conditions. On the whole, the William Lyon and the Mill "A" records show a rational relationship to the true mean lake level as derived from the records of the last few years. They do not, however, show a rational relationship to the lake level recorded by the gauge readers of the Department of Public Works, Ontario, during the earlier years. During the summer of 1900, for example, the Public Works records indicate a practically uniform lake stage, whereas the Mill "A" and the William Lyon records indicate a distinctly falling stage. Because of such facts the mean lake level line for 1900, 1901 and 1902 is based largely on the Mill "A" and the William Lyon records, giving due consideration to the relationship shown to exist between these fore bay records and the true lake level during later years.

From November 10th, 1900, on through December, and for January and part of February, 1901, the Public Works records again appear to be in error. The Mill "A" tail water records show a uniform rise. Apparently no change was made in the stop logs at the dam, after November 10th, and yet the Public Works records show a rapidly falling lake stage. The William Lyon fore bay records of November 2nd, 3rd, 9th, and 16th, indicate a gradual rise in lake level. The Mill "A" fore bay records also indicate a gradual rise in lake level during November with perhaps a slowly falling level in December. Respecting December, however, the fact is not well established, as there is only one reading given for this month. The fact that the Mill "A" reading of Sunday, November 4th, 1900, practically coincides with the Public Works reading for this date, when taken in connection with the previous and the following days' readings, indicates that there was a fall of approximately .7 foot between the Lake and the fore bay at this time.

For the purpose of establishing the accuracy of the adopted mean level line for November, 1900, assume the tail water level constant at 1046.35 for this month. A tail water level of 1046.35 corresponds to a discharge of 39,705 c. f. s. The rise in lake level of about .3 foot recorded by the Public Works gauge reader between November 1st and 11th, corresponds to an increase in lake storage equivalent to 14,375 c. f. s. This storage, combined with an outflow of 39,705 c. f. s., gives a runoff equivalent to 54,080 c. f. s. The drop in lake stage of .5 foot recorded between November 11th and 25th, corresponds to a decrease in storage of 17,000 c. f. s., or a runoff into the Lake for this period of only 22,705 c. f. s. From November 25th to December 12th, the Public Works records show a constant lake stage which would indicate that the runoff was equal to the outflow, or 39,705 c. f. s. Such a rapid fluctuation in runoff at this time of the year, under normal meteorological conditions, is a physical impossi-

bility, consequently we have selected a mean lake level of 1062.35 on November 30th, and have assumed a gradual reduction in lake stage to February 16th, 1901.

The fluctuation in lake stage indicated by the Public Works records for May, 1901, cannot be satisfactorily accounted for, and the mean lake level line for this month has again been based mainly upon the William Lyon and the Mill "A" records.

During November, 1901, the Public Works records again show a fall in lake stage which, as may be seen from a simple computation, could not have occurred. From October 15th to December 1st, 1901, an average tail water level of 1038.0 is recorded. This corresponds to a discharge of 11,720 c. f. s. The decrease in lake stage of .5 foot recorded by the Public Works gauge reader, between November 3rd and 13th, corresponds to a decrease in storage equivalent to 23,958 c. f. s., or a negative runoff of 12,238 c. f. s. At a temperature of 30 degrees, prevailing at this time, the evaporation from the surface of the Lake would be about one inch per month, equivalent to 1,325 c. f. s. Subtracting this evaporation loss from the indicated negative runoff of 12,238 c. f. s., still leaves 10,913 c. f. s. *plus all of the inflow* into the Lake unaccounted for. The Public Works records from November, 1901, to May, 1903, are, therefore, not given much weight, and the mean lake level line is based principally upon the William Lyon and the Mill "A" fore bay records, with due compensation for fall between Lake and fore bays.

During the summer of 1903 the Warroad and the Mill "A" records are used as the basis for determining the mean lake level. The Public Works records are not given any weight for most of this period because the Mill "A" fore bay records, on May 30th and on June 12th, which are not Sundays, show higher readings than the Public Works records, and further, because of the fact that Napoleon Lemay was the Public Works gauge reader at this time. The character of his observations has been previously commented upon.

The single record of head water level taken at Kenora by A. Pringle on July 29th, 1903, is also platted on the graph. When allowance is made for fall from the Lake to the head race, this record confirms the mean lake level line adopted. The Public Works records for August 28th to 30th check with the Warroad records, and the mean lake level line is drawn through these points.

During September and October, 1903, heavy precipitation was recorded over the entire Lake of the Woods watershed. This fact, together with a statement accompanying the gauge readings both in the Public Works Record Book and on the Sheets, to the effect that these records are according to instructions received from the Government Inspector, Mr. Burton, led to the acceptance of the Public Works records for the first two weeks in November, 1903. From that

point on, however, it is again assumed that the Lake fell gradually until April, 1904.

On March 11th, 1904, the late Mr. R. Davenport, of the U. S. Engineer Office at St. Paul, Minnesota, made an instrumental determination of the water level at Warroad. The elevation of water surface, viz. 1058.69, as determined by Mr. Davenport, is accepted as the mean lake level for that date. This agrees well with the Mill "A" fore bay and the William Lyon records. The drop indicated by the first six days' gauge readings at Warroad during April, 1904, argues an impossible lake condition, and hence the records for these days are disregarded. From this point on, however, the Warroad records show a consistent relationship to the Mill "A" records, and, during the remainder of the year 1904, are used largely as the basis for determining the line of mean lake levels.

Throughout 1904 and 1905, the Warroad records have been followed consistently, checked by the Public Works records from September 11th to 17th, 1905, the latter part of October and all of December, 1905. The Warroad records also agree with the records furnished by the Ontario Hydro-Electric Power Commission between October 4th, 1905 and May 18th, 1906.*

The mean lake level line adopted for the winter of 1904 and 1905 is based, primarily, upon the January 11th reading at Warroad, and the Mill "A" fore bay records. The William Lyon records also agree with the line of mean lake levels adopted.

The instrumental checks of the Warroad gauge on March 11th, 1904, and December 16th, 1905, at practically the beginning and end of the two years in question, add confidence in the reliability of the Warroad records for this period. Moreover, Lemay was gauge reader at Keewatin during 1904 and up to April, 1905. During the summer of 1905, the dock at Norman is said to have been in an unstable condition, and except for readings in September and October (which are assumed to have been taken by Hansen from his mark) the records of lake levels are unreliable until December, 1905, at which time the gauge was being read at the Keewatin bridge, presumably having been transferred during November of that year.

From March until September, 1906, the records for the various stations do not check well. The William Lyon record of April 10th and the Mill "A" fore bay record of April 18th indicate that the Keewatin records are too low, and that a line through the Ontario Hydro-Electric Power Commission's records would be more nearly correct. On May 27th, 1906, the following note appears relative to Mill "A": "Sunday Mill not running, south wind"; and on June

*The bench marks establishing the Ontario Hydro-Electric Commission datum, to which their gauge was referred, have been destroyed. These records, however, have been reduced to sea-level datum by adding 457.2 feet. This equation has been derived from a comparison of the various available gauge records or this period, corrected for a slight fall through the Devil's Gap.

3rd, 1906: "Sunday not running." It seems reasonable to assume that these two days give actual lake levels. If so, then Warroad records at this time appear several tenths too high and Keewatin about .1 low. This condition is assumed to prevail throughout the summer until September, when both the two stations practically give the same level.

The Kenora head water levels, taken by Mr. G. M. Wynn during a portion of 1906, are also plotted on the graphs, and confirm the line of mean lake level adopted.

During the latter part of 1906, and through all of 1907, both Warroad and Keewatin records gave a reliable mean lake level.

In August, 1907, the Kenora Municipal Power Plant fore bay records begin. Although this gauge, as a rule, records water levels somewhat below the lake stage, nevertheless, these records are of value, and on Sundays, when little or no water is being used by the plant, the gauge should record a water level practically as high as that in the Lake. During the latter part of 1907, the Kenora fore bay records give higher stages than the Keewatin lake gauge records. On Sunday, November 24th, 1907, and on Sunday, December 22nd, 1907, the Kenora fore bay gauge, as might be expected, appears to record very nearly the actual lake level.

From 1908 to 1912 several records of lake levels taken by Mr. George Drewry, at his boat house in Kenora, are available and are extremely valuable in determining the mean lake level in several instances.

The following notes, appearing with the Mill "A" records, are of assistance in determining mean lake levels during 1908. On January 25th, 1908: "Mill closed down"; on March 12th, 1908: "Mill closed, 17 logs removed at Dam 2nd to 7th"; and on July 2nd: "Mill closed down." From March to August 1908, the Mill "A" fore bay levels lie well up among the lake levels and consequently may indicate that Mill "A" was shut down for a considerable portion of this time. The records of all gauges for June 5th, June 27th, August 3d and 4th, August 16th to 22nd, October 27th, and all of December, 1908, are merely a few of those which stand out in importance in deriving the mean lake level for this year.

During 1909, as in other years, the effect of wind is manifested by a lowering of the lake surface at Keewatin and Kenora, and a rising at Warroad, or vice versa. The phenomenon, occasionally, is of use in determining whether or not one or the other of the Lake of the Woods gauges was actually read daily during a certain period. On November 14th, 1909, Warroad records a very high level and Kenora fore bay a very low level, while the Keewatin record shows the same stage from November 14th to December 18th, indicating

that during the latter part of November, at least, no correct readings were actually taken.

During May, 1909, the Drewry records agree with the Warroad records, and consequently these two are used.

On the Sundays, December 26th, 1909 and January 16th, 23rd, and 30th, 1910, the readings of the Kenora Power Plant fore bay gauge, are used in determining the mean lake levels because both the Keewatin and the Warroad records appear of questionable accuracy.

From February, 1910, to the latter part of June, 1910, there is little difficulty in determining the mean lake level. During July, August, September, and most of October, the mean lake level line is based principally on the Drewry, the Kenora, and the Warroad records—the Keewatin records not being consistent. In April, 1910, following note appears on the Mill "A" records: "Mill closed, 40 more stop logs taken out on April 26th"; on May 3rd, 1910, this note: "Mill closed"; and on May 21st and 25th, 1910: "Mill A closed." These notes indicate that Mill "A" was closed during a portion of April, May, and June, and would account for the fact that the Mill "A" fore bay gauge, records water levels agreeing with those recorded by the lake gauges. As instances of close correspondence between the records of the lake gauges, more particularly of the Drewry, Kenora, and Warroad gauges, the following dates may be cited: April 19th, April 25th, May 13th, June 14th, July 7th, October 20th, November 6th, and November 12th, all in 1910.

During the winter of 1910 and 1911, Sunday falls on December 4th, 11th, 18th, and 25th, and January 1st, 8th, 15th, 22nd, and 29th. The mean lake level for these two months is based principally upon the Sunday readings of the fore bay gauge of the Kenora Municipal Power Plant—after making a small allowance for fall. As previously noted, the Warroad gauge heights, from January 1st, 1911, to April 27th, 1912, taken at Zippel, are not considered reliable, consequently, the mean lake level during this period is based upon the Drewry, the Keewatin, and the Kenora records. Close correspondence between these records may be noted in particular on the following dates: April 17th, June 8th, June 29th, September 10th, and November 14th, in 1911.

During the winter of 1911 and 1912, Sunday falls on December 3rd, 10th, 17th, 24th, and 31st; January 7th, 14th, 21st, and 28th; February 4th, 11th, 18th, and 25th; March 3rd, 10th, 17th, 24th, and 31st; and April 7th, 14th, 21st, and 28th. It will be noticed that the Kenora fore bay records for these dates stand out significantly, and it is these records which are used, primarily, in arriving at mean lake levels through the winter of 1911 and 1912. As stated before, the

Warroad records from December 1st, 1911, to April 28th, 1912, are considered so unreliable that it was deemed best not to plot them.

It will be noticed that on April 4th, 1912, there is very close correspondence between the Drewry and the Keewatin records.

From April 28th, 1912, to date, all of the gauges have been read with sufficient care to yield reliable records, and the mean lake level line is readily determined by giving proper weight to wind effects at the two ends of the Lake. The difference in the character of the gauge records during the earlier and the later years covered by our investigation is so apparent from the graphs as to require no comment.

We believe, however, that the mean lake level line as we have deduced it from all available data constitutes a substantially correct record of the levels which have prevailed on the Lake of the Woods from October 1st, 1892, to December 31st, 1915.

OUTFLOW FROM THE LAKE OF THE WOODS

INTRODUCTORY COMMENTS

The only measurements of outflow from the Lake of the Woods made prior to June, 1912, are given in Table 59.

Since June, 1912, the Manitoba Hydrographic Survey, of the Water Power Branch, Department of the Interior, Canada, has made frequent measurements, by approved methods, of the outflow from the Lake through the various channels. A summary of these measurements is presented in Tables 53 to 57.

Even though practically no meter measurements were made of the outflow from the Lake of the Woods through the various channels, until recent years, yet reasonably continuous records of water levels below the mills, and below the Norman Dam, have been kept since 1892. The physical conditions at the outlets of the Lake, and in the Winnipeg River for some distance below Kenora, are such that it is entirely feasible to deduce the outflow from the Lake, during the earlier years, by means of the readings of the tail water gauges at the mills and at the Norman Dam, after the relation between tail water level and discharge has been determined from the recent measurements of the Manitoba Hydrographic Survey.

The outflow from the Lake of the Woods, from 1892 to date, as computed from the tail water levels at Keewatin and the rating curve of "Discharge through all Outlets," Plate 70 (which will later be discussed), is given in Table 70.

SUMMARY OF AVAILABLE TAIL WATER RECORDS

The following records of water levels in the tail races of the mills and the power plants at Keewatin and at Kenora, and in the river below the Norman Dam, are available for the period of years from 1892 to date.

	Table	Plates
1. Records of James C. Kennedy, Engineer for the Keewatin Power Company: Tail water levels observed at the site of the Norman Dam, at Norman, Ontario, from October, 1892, to October, 1895, and from July to December, 1898	6	51, 52, 54
2. Records of the Department of Public Works, Ontario: Tail water levels observed at Norman, Ontario, from November, 1898, to about September, 1908, and at Keewatin, Ontario, from about September, 1908, to date	7	54 to 64
3. Records of the Lake of the Woods Milling Company: Tail water levels taken with the chain gauge in the tail race of Mill "A", at Keewatin, Ontario, several times a month during most of the period from 1896 to 1912	9	53 to 64

	Table	Plates
4. Records of the Kenora Municipal Power Plant: Tail water levels observed at Kenora, Ontario, on the river gauge and on the tail race gauge of the Power Plant, from August, 1907, to date	10	61 to 65
5. Record of Mr. A. Pringle: Tail water level observed at Kenora, Ontario, on July 29th, 1903		59
6. Records of Mr. G. M. Wynn: Tail water levels observed at Kenora, Ontario, during the construction of the present Municipal Power Plant, on occasional days from June to October, 1906	20	61
7. Records of the Manitoba Hydrographic Survey: Tail water levels observed at the Winnipeg River Bridge at Keewatin, Ontario, from June 29th, 1912, to date	14	64 and 65
8. Records of the Manitoba Hydrographic Survey: Tail water levels observed at the Norman Dam, at Norman, Ontario, from October 8th, 1913, to December 31st, 1914	14	64 and 65
9. Records of the Manitoba Hydrographic Survey: Tail water levels observed on the river gauge and on the tail race gauge of the Power Plant, at Kenora, Ontario, from August, 1912, to February, 1913	22	64

RECORDS OF JAMES C. KENNEDY AT NORMAN, ONTARIO

The tail water levels observed by Mr. James C. Kennedy, or under his supervision, were taken in the pool below the rapids at the site of the Norman Dam, from October, 1892, to October, 1895, and from July to December, 1898. According to the records, on October 14th, after the completion of the dam, Kennedy established a gauge "at the tail end of fishway."

As explained fully when discussing Kennedy's lake levels, the readings of his gauges have been reduced to sea-level datum by the addition of 960.0. Kennedy's observed tail water levels appear in Table 6, and are shown graphically on Plates 51, 52, and 54.

RECORDS OF THE DEPARTMENT OF PUBLIC WORKS, ONTARIO, AT NORMAN AND KEEWATIN ONTARIO

On November 19th, 1898, after completion of the Norman Dam, the operation of the structure was turned over, by the Keewatin Power Company, to Alexander McQuarrie, caretaker appointed by the Ontario Government. Practically continuously since that date, tail water levels have been observed by various gauge readers of the Department of Public Works, Ontario. The original gauge set by James C. Kennedy in October, 1898, or a gauge similarly placed and reading to the same datum, was used up to November, 1905. At this time, according to information furnished by the Manitoba Hydrographic Survey, when the lake gauge was transferred from Norman to Keewatin, the "Above Dam" and "Tail Water" gauges at the Norman Dam were re-set.

The new "Above Dam" gauge consisted merely of a notch, regarded as being at elevation "100," in the corner of the fishway pier, from which measurements were taken to the water level. The zero of this gauge, as determined by the Manitoba Hydrographic Survey in 1912, is 961.6. It has been stated that, at the time these gauges were re-set, the levels were transferred from the "Above Dam" gauge to the lower end of the fishway, by means of a carpen-

ter's level, and the "Tail Water" gauge thereby re-established. A photograph of this gauge, fastened to the lower end of the fishway, presumably in the fall of 1905, is shown on Plate X. The instrumental checks of this gauge, made by the Manitoba Hydrographic Survey, follow.

Determination of Zero
Public Works Tail Water Gauge
Norman, Ontario

June 21, 1912, Zero of Gauge, sea-level datum	960.74
Nov. 14, 1912, Zero of Gauge, sea-level datum	960.73
June 9, 1913, Zero of Gauge, sea-level datum	960.68

During 1907 or 1908 a gauge is stated to have been established on a timber crib at the exit of the tail race of Mill "C" of the Lake of the Woods Milling Company at Keewatin. Both this and the Norman Dam tail water gauge are stated to have been read for some time as a check, and then the readings at the Norman Dam were discontinued. No definite time has been given as the date of the beginning of readings at the Mill "C" gauge, but as near as it is possible to determine the time by the records, readings were begun at this gauge about September, 1908.

During the low water prevailing in the fall of 1911, the stability of the crib to which the gauge at Mill "C" was attached, became endangered through undermining, and the datum of this gauge was transferred, by water level, to the old chain gauge in the tail race of Mill "A." Some time later the gauge at Mill "C" was destroyed.

Readings of tail water levels at Mill "A" were made on the chain gauge by lowering a weight in the tail race of the mill. At the time of transfer in the fall of 1911, a scale was established on the wall of Mill "A," so that readings were given directly. This chain gauge was destroyed about June 23rd, 1912, during the reconstruction of the mill.

From a point on a rock in the tail race, corresponding to a gauge reading of 74.0 (local datum), as given by the gauge reader, a staff gauge, reading to the same datum as the old chain gauge, was established on June 24th, 1912, by the Manitoba Hydrographic Survey, in the Winnipeg River just outside the tail race. A photograph of this gauge is shown on Plate T. The various instrumental checks made of the zero of this gauge, by the Manitoba Hydrographic Survey, follow.

Determination of Zero
Public Works Tail Water Gauge
Keewatin, Ontario

June 25, 1912, Zero of Gauge, Sea-level Datum	960.29
July 17, 1913, Zero of Gauge, Sea-level Datum	960.33
Dec. 8, 1913, Zero of Gauge, Sea-level Datum	960.34

Feb. 3, 1914, Zero of Gauge, Sea-level Datum	960.34
Feb. 26, 1914, Zero of Gauge, Sea-level Datum	960.34
Apr. 10, 1914, Zero of Gauge, Sea-level Datum	960.33
May 30, 1914, Zero of Gauge, Sea-level Datum	960.34
July 8, 1914, Zero of Gauge, Sea-level Datum	960.37
Aug. 7, 1914, Zero of Gauge, Sea-level Datum	960.38
Sept. 14, 1914, Zero of Gauge, Sea-level Datum	960.345
Oct. 1, 1914, Zero of Gauge, Sea-level Datum	960.34
Dec. 11, 1914, Zero of Gauge, Sea-level Datum	960.345

In the reduction of the Department of Public Works, Ontario, tail water records to sea-level datum, a gauge zero of 960.0, or that used for the Kennedy records, was applied from November, 1898, to November, 1905. From December, 1905, to September, 1908, a gauge zero of 960.7, i. e., the zero of the old Norman Dam tail water gauge, as determined in 1912 and 1913 by the Manitoba Hydrographic Survey, was applied.

During the water level transfers from the Norman Dam tail water gauge to the Mill "C" gauge, and from there to the Mill "A" chain gauge, an error of about 0.4 of a foot was apparently made. This may be observed by a comparison of Tables 7, 9, and 10. A part of this error can be accounted for by the fall of from one to three tenths of a foot between the Norman Dam and Keewatin, at low and high stages, respectively.

It has been assumed that in the water level transfer from Mill "C" to the Mill "A" chain gauge no error was involved, and that the gauge zero of 960.3, as given in the above table, held from September, 1908, to June, 1912, when the first instrumental check was secured. Since June, 1912, the Department of Public Works records have been reduced to sea-level datum by the gauge zeros given in the above table. These records appear in Table 7, and are shown graphically on Plates 54 to 64.

RECORDS OF THE LAKE OF THE WOODS MILLING COMPANY AT KEEWATIN, ONTARIO

Tail water levels observed by means of the chain gauge at Mill "A," by employees of the Lake of the Woods Milling Company, were taken at irregular intervals between 1896 and 1912. The distance from the top of the power house floor to the water level was measured, at times, in both fore bay and tail race, so as to obtain the head utilized by the turbines of the mill. The readings were made in feet and inches below the top of the floor, the elevation of which was found, in 1912, by the Manitoba Hydrographic Survey to be 1064.31. The fore bay readings were made by means of a graduated stick, while those in the tail race were made by means of the chain gauge, a weight being lowered until it touched the water surface. These records appear in Table 9, and are shown graphically on Plates 53 to 64.

98896—17—10

RECORDS OF THE KENORA MUNICIPAL POWER PLANT AT KENORA, ONTARIO

Daily tail water readings are available, of the Kenora Municipal Power Plant river gauge, from August 21st, 1907, to November 2nd, 1910, and of the tail race gauge above the submerged weir, from November 3rd, 1910, to the present time. These readings were taken by employees of the Power Plant for the purpose of obtaining the head utilized at the plant.

The river gauge was located just around the first point on the right shore below the power house, as shown on the "Key Plan of Outlets, Lake of the Woods." During the low water of the fall of 1910, the old cofferdam below the power house was built up so as to form a weir to keep the tail water level up sufficiently high to prevent the breaking of the vacuum in the draft tubes. The construction of the weir necessitated the establishment of a gauge above it, in order to obtain the head utilized, particularly in low water, consequently, about November 1910, a new gauge was placed in the tail race immediately below the power house. Readings were taken on both gauges until January 16th, 1912, when the old river gauge was abandoned. The records of these gauges, as platted on Plate 64 indicate that the Kenora tail water readings may have been taken at the gauge above the cofferdam after November 3rd, instead of after December 1st, 1910—the date given by the Manitoba Hydrographic Survey—as has been stated.

The instrumental checks of these gauges, as made by the Manitoba Hydrographic Survey, follow.

Determination of Zero, Municipal Power Plant Tail Water Gauges, Kenora, Ontario

Sept. 21, 1911, Zero of Old River Gauge, Sea-level datum	962.97
June 24, 1912, Zero of New River Gauge, Sea-level datum	962.875
June 24, 1912, Zero of Tail race Gauge, Sea-level datum	962.875
Mar. 3, 1913, Zero of Tail race Gauge, Sea-level datum	962.89
Mar. 3, 1913, Zero of Tail race Gauge (Re-set), Sea-level datum	962.675
Sept. 27, 1913, Zero of Tail race Gauge, Sea-level datum	962.675
Sept. 28, 1913, Zero of Tail race Gauge, Sea-level datum	1001.31

In accordance with the above values a gauge zero of 963.0 was used for reduction purposes from August 21st, 1907, to November 30th, 1910; of 962.9 from December 1st, 1910, to March 2nd, 1913; and of 962.68 from March 3rd, 1913, to September 27th, 1913, after which date the gauge was set to read directly to the Water Power Survey datum of the Manitoba Hydrographic Survey, with a zero of 1001.31 sea-level datum. These records appear in Table 10, and are shown graphically on Plates 61 to 65.

A picture of the Kenora Municipal Plant tail race gauge is shown on Plate T.

RECORD OF MR. A. PRINGLE AT KENORA, ONTARIO

A single observation of tail water level, elevation 80.36, local datum, was made by A. Pringle and J. S. Costigan on July 29th, 1903, at the time they made their meter measurement of the flow through the Eastern Outlet. The reading was referred to the local datum used during the construction of the Kenora Power House, and when reduced to sea-level datum by the addition of 962.63, gives a valuable record of the relation between tail water levels at Kenora and at Keewatin. This record appears on Plate 59.

RECORDS OF MR. G. M. WYNN AT KENORA, ONTARIO

During the construction of the present Kenora Municipal Power Plant in 1906, scattered readings of tail water levels were taken by Mr. G. M. Wynn, then resident engineer. These records were taken at the first point on the right shore, below the power house, and were referred to the local datum used in the construction of the plant, the elevation of which is 962.63 feet above sea-level datum. These readings are of considerable value in that they give the relation between Kenora and Keewatin tail water levels when the Eastern Outlet was entirely closed off. These records appear in Table 20 and are shown graphically on Plate 61.

RECORDS OF THE MANITOBA HYDROGRAPHIC SURVEY AT KEEWATIN

On June 25th, 1912, the Manitoba Hydrographic Survey established a gauge on the southern end of the Winnipeg River Traffic Bridge at Keewatin. Daily, or twice daily readings have been taken on this gauge, from June 29th, 1912, to the present time, except between December 4th, 1912, and March 10th, 1913, when the readings are scattered. On January 12th, 1914, the gauge was removed from the bridge and placed on the right bank of the River a short distance below the bridge. Beginning with January 1st, 1914, the readings are given directly to Water Power Survey datum. The instrumental checks of this gauge follow.

Determination of Zero, M. H. S. Keewatin River Bridge Tail Water Gauge—Keewatin, Ontario

June 25, 1912, Zero of Gauge, Sea-level Datum	961.15
Nov. 21, 1912, Zero of Gauge, Sea-level Datum	961.17
July 17, 1913, Zero of Gauge, Sea-level Datum	961.19
Jan. 12, 1914, Zero of Gauge, Sea-level Datum	961.18
Jan. 12, 1914, Zero of Gauge, Sea-level Datum	1001.31
Jan. 31, 1914, Zero of Gauge, Sea-level Datum	1001.31

The records appear in Table 14, and are shown graphically on Plates 64 and 65.

A picture of this gauge is shown on Plate T.

RECORDS OF MANITOBA HYDROGRAPHIC SURVEY AT NORMAN

From October 8th, 1913, to December 31st, 1915, daily readings of the Norman Dam tail water gauge have been taken by the Manitoba Hydrographic Survey. These readings have been taken direct to Water Power Survey datum, and when reduced to sea-level datum afford a comparison between tail water levels at Norman and at Keewatin. The relationship found to exist between tail water levels observed at these two points from 1913 to 1915, and which is corroborated by a few earlier readings, is used in deducing mean tail water levels at Keewatin for the early years, from the readings taken at Norman.

The relation between tail water levels at Norman and at Keewatin, for the same discharge through the West Branch of the Winnipeg River, used in deducing mean tail water levels at Keewatin from the readings at Norman during the early years, is based upon the relationship found to exist between these two points from 1913 to 1915, and which is corroborated by a few earlier readings.

These records appear in Table 14, and are shown graphically on Plates 64 and 65.

RECORDS OF MANITOBA HYDROGRAPHIC SURVEY AT KENORA

Beginning August 1st, 1912, and continuing until February 19th, 1913, daily readings of the Kenora river and tail race gauges were taken by the Manitoba Hydrographic Survey. These readings afford a comparison between tail water levels at Kenora and at Keewatin.

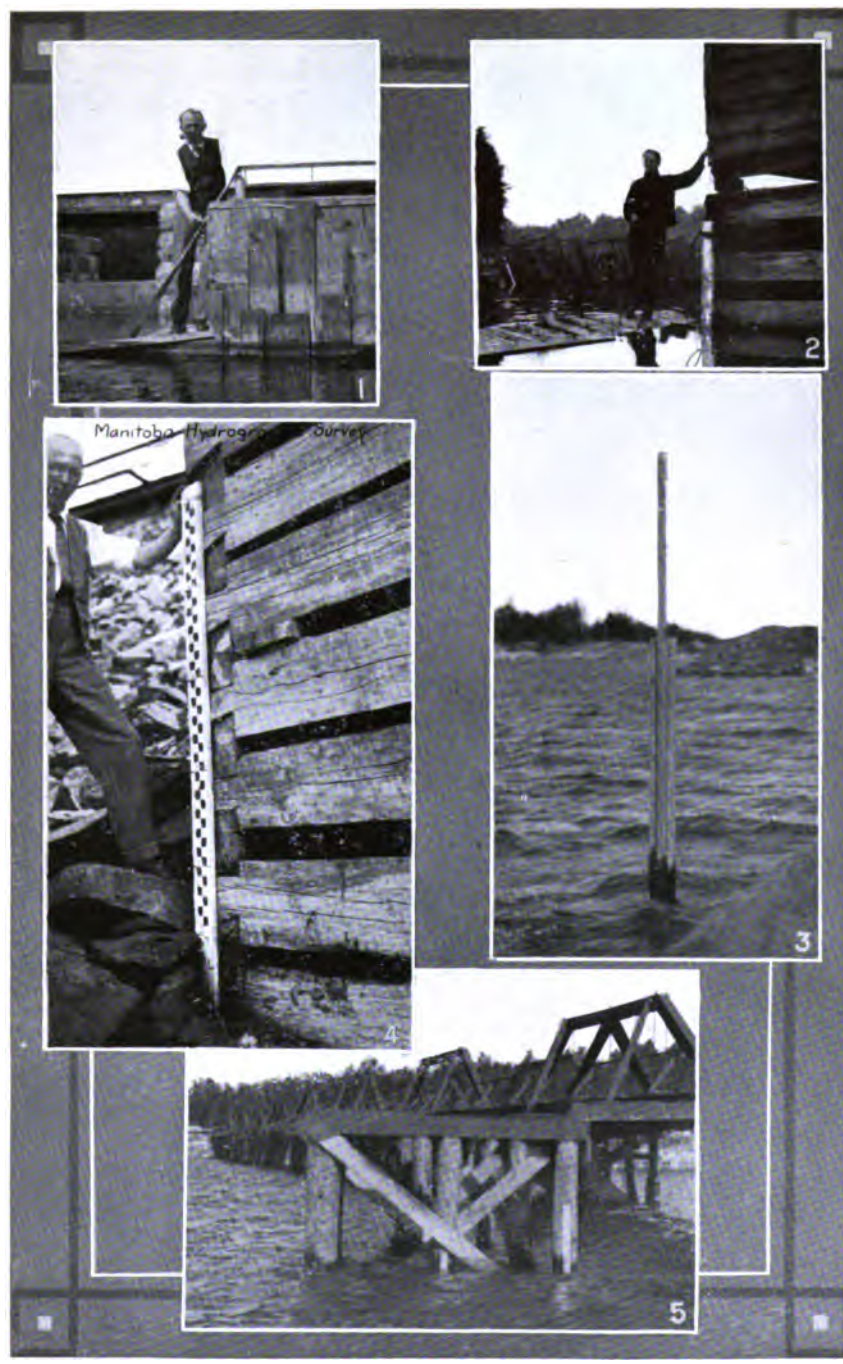
These records appear in Table 22, and are presented graphically on Plate 64.

DETERMINATION OF MEAN OBSERVED TAIL WATER LEVELS AT LAKE OF THE WOODS

From October, 1892, to October, 1895, tail water levels were observed at the Norman Dam under the supervision of Mr. James C. Kennedy. The records for this period are accurate, and the mean level at Keewatin is readily determined by allowing for differences in level between Norman and Keewatin. Except for the one record of March 15th, 1893, which appears to be in error, the line of mean tail water level at Keewatin closely follows the Kennedy readings. The line has been drawn from .1 to .2 of a foot below the mean observed level at Norman, to compensate for the higher reading of the tail water gauge at Norman. Tail water readings at Keewatin can then be used directly in the determination of discharge from the Keewatin rating curve.

As previously stated in discussing mean lake levels, it is necessary to estimate tail water levels between October 10th, 1895, and May 4th, 1896. As explained in detail in that discussion, a tail

PLATE T



Courtesy of Manitoba Hydrographic Survey (1, 2, 4)

1. MR. SCOVIL HOLDING FINGER ON "100" NOTCH OF 'ABOVE DAM GAUGE' AT NORMAN, ONTARIO
2. PRESENT TAIL RACE GAUGE OF KENORA MUNICIPAL POWER PLANT
3. PUBLIC WORKS TAIL WATER GAUGE BELOW MILL "A" AT KEEWATIN—SEPTEMBER 11, 1913
4. PRESENT NORMAN DAM TAIL WATER GAUGE
5. MANITOBA HYDROGRAPHIC SURVEY TAIL WATER GAUGE ON KEEWATIN RIVER BRIDGE—SEPTEMBER 11, 1913

water elevation of 1036.0 for April 1, 1896, was estimated by comparison with previous years. The mean line was then given a gradual slope downward from October 10th, 1895, to April 1st, 1896, and a slope upward from April 1st to May 4th, 1896, in accordance with similar changes in previous years.

Throughout 1896, 1897, and part of 1898, the Mill "A" records are the only ones available, and hence are used in determining the mean tail water level.

During the latter part of 1898, close correspondence between the Mill "A" and Kennedy records is noticeable. During periods of low discharge through Mill "A", and during periods of medium to high tail water stages, the Mill "A" tail water records have, in the absence of any further information, been considered as giving true Keewatin tail water levels. An inspection of the graphs will substantiate this conclusion. Occasionally, especially at the lower stages, the Mill "A" tail water level is found to lie several tenths above the mean line, on account of the fall through tail race proper.

On September 22nd, 1911, at the low stage of 1035.51 at Keewatin, there was a fall of 0.48 foot between the water level inside of tail race and that in the River below.

The variations of tail water level in the fall of 1898 are due to the manipulation of the stop logs in the sluices at the dam, as explained in the notes accompanying the records.

The variations in tail water level during the latter part of April and fore part of May, 1899, were also due to stop log manipulation. The old Rollerway Dam is stated to have been removed between May 1st and 13th, 1899.

According to the records, all the stop logs were removed from the Norman Dam by June 11th, 1899. Driftwood apparently accumulated at the dam during the high water of June and July, but, according to the statement of the gauge reader, it did not affect the free discharge of water through the dam. The Public Works records show a peculiar variation in stage during July, August, and part of September, 1899. This variation does not appear to represent actual physical conditions, and consequently, the mean tail water level line is passed through the Mill "A" readings. The large drop in tail water level during October and the rise in December were both due to the manipulation of stop logs at the Norman Dam.

From the last half of December, 1899, to April, 1900, the Mill "A" readings are about a foot higher than those of the Public Works Department, but are believed to be correct for the following reasons. First—About 74 stop logs were out of the dam during the winter of 1899 to 1900. These were replaced about April 1st. A substantial drop in tail water would then be expected about April 1st. This

drop is very manifest in the Mill "A" readings, but is barely indicated by the Public Works records. Second—The greater the number of stop logs taken out or put into the dam, the greater, generally speaking, should be the corresponding change in tail water level, other conditions remaining constant. In December, 1898, the removal of 52 logs resulted in a rise of 1.7 feet in tail water. In December, 1899, the removal of 74 logs, at higher lake and tail water stages, resulted in a rise in tail water level of 2.6 feet, according to the Mill "A" readings, and only 1.6 feet according to the Public Works readings. For these reasons, the Mill "A" records are accepted and used as the basis for the mean tail water level line during the winter of 1899–1900.

The rise in tail water, shown by the Public Works records previous to September 26th, 1900, cannot be satisfactorily accounted for. No change was made in the dam until the 26th, when two large and three small logs were removed. The increased tail water level, then, resulted from increased discharge through the Eastern Outlet and increased leakage through the Norman Dam, as the result of increased lake stage. The Public Works records would show an increase in leakage through the dam of about 2300 c. f. s., for a rise of about 2 feet in lake stage, from August 20th to September 25th, after making due allowance for increased discharge through the Eastern Outlet, and assuming a constant flow of about 1050 c. f. s. through the Keewatin mills. The mean tail water line, based on the Mill "A" records, shows an increased leakage of about 900 c. f. s. The adopted line is believed to be correct, inasmuch as an increase of 2300 c. f. s. would be between 35 and 40 per cent of the total leakage at that time, which is unquestionably too large.

During the winter of 1900 to 1901, the Public Works records again fail to agree with the Mill "A" records. No gauge heights are recorded at Mill "A" between December 13th, 1900, and February 23rd, 1901, but the following note, by the Mill "A" gauge reader, appears, "Ice frozen out too far to measure correct but has kept gradually falling below as well as above." The Public Works records show no fall whatever until after February 23rd, when they agree with the Mill "A" records, consequently, for the days on which they are available, the Mill "A" records have been accepted for the entire period from October, 1900, to February, 1901. The Mill "A" reading on April 12th, 1901, is probably in error 1 foot.

It is probable that the Public Works records between August 24th and October 13th, 1901, do not represent actual readings. It appears as though the gauge had been read on August 24th, 1901, when the work of replacing stop logs was completed, and then estimated for some time following. The gauge reader apparently assumed, inasmuch as stop log removal had been completed, that the

tail water level would remain constant. A number of similar instances can be found on the graphs, as for example,

1. Period following removal of logs completed October 15–17, 1900.
2. Period following replacing of logs completed August 23, 1901.
3. Period following replacing of stop logs in progress July 23, 1902.
4. Period following replacing of stop logs in progress September 3, 1902.
5. Period following removal of stop logs in progress May 5, 1903.

While of minor importance, the following dates indicate additional instances on which the Public Works gauge does not seem to have been read daily: June 18 to 28, September 25 to 30, October 7 to 9, October 15 to 25, December 16 to 31, all in 1899; April 6 to 23, 1900; May 12 to 16, 1901; July 9 to 19, 1902; April 15 to May 3, 1903; and frequently in 1904.

During the entire year of 1902, the Public Works records again do not agree with those of Mill "A," and the mean tail water level line is based on the latter records. In June, for example, the Public Works records gives 1046.3, which is almost up to the high water of 1900. This could not possibly be correct, because the stop logs were not all out of the dam, and the lake level was lower than in 1900, at which time the dam was practically wide open.

The drops in tail water level in July and September resulted from the placing of stop logs in the dam. There is no record, however, of any change in the dam in October, 1902. It appears as though the gauge reader had suddenly discovered that his previous readings were in error by about 1 foot.

From January to March, and during November and December, 1903, the Public Works records and the Mill "A" records agree. Lemay began reading the Public Works gauge in August, 1903. Except for November, 1903, when, according to the notes, the readings were taken "according to the instructions given me by Mr. Burton, Government Inspector", Lemay's records are very unreliable,—a fact indicated in the previous discussion of the Public Works records.

In 1904, on account of discrepancies in Lemay's readings, the Mill "A" records are again followed. The more noticeable irregularities in Lemay's records for the year, are the rise of 1.05 feet from May 12th to 13th, and the similarity between the readings for the first and the last half of February, July, and December. The one high gauge record at Mill "A" on November 7th, 1904, is substantiated in a general way by the apparently approximate readings of Lemay, and the note appearing on that day in the Mill "A" records "Stop logs out to remove driftwood".

In April, 1905, N. K. Hansen was appointed caretaker of the Norman Dam. Apparently he did not read the gauge correctly during the first two months. During the months of high discharge which followed, however, his readings appear reliable. During September and part of October, the Mill "A" records appear to be about 1 foot in error. This conclusion is substantiated by the note appearing in the Mill "A" records, September 14th, 1905, "Heavy rain, east wind, started putting in few stop logs on 13th". Evidently the drop of 1 foot in the Mill "A" readings on September 1st was not due to the replacing of stop logs, and presumably represents an error of 1 foot in the gauge reading.

Close correspondence between the Mill "A" and Department of Public Works records between April 24th and June 7th, 1906, is noticeable.

Several water levels, obtained by G. M. Wynn during the construction of the present Kenora Power House, have been reduced to sea-level datum and platted on the graph of observed tail water levels for 1906. With the Eastern Outlet entirely shut off, the tail water level recorded at Kenora would be lower than that at Keewatin. A comparison of Wynn's June and July readings with the Mill "A" records indicates a fall between Keewatin and Kenora of about 0.75 foot at a stage of 1042.5, and no discharge through the Eastern Outlet. During June, 1913, when the Kenora Power Plant was discharging approximately 1200 c. f. s. on week days, this fall was approximately 0.5 foot at a tail water level of 1041.4 at Keewatin. Between August 5th and September 19th, 1913, with a tail water stage of 1039.5 at Keewatin, the Kenora plant discharged an average of about 700 c. f. s. The fall at this lower stage is 0.55 to 0.60 foot, which is very likely due to the decreased discharge.

The tail water record of Pringle on July 29th, 1903, gives a fall of 0.70 foot at a stage of 1043.7, and a discharge of 4122 c. f. s. through the Eastern Outlet. On Sunday, October 4th, 1914, at 10:30 A. M., the Kenora gauge read 1037.76 as against a reading of 1038.46 at Keewatin at noon, or a fall of 0.70 foot with a very low discharge at Kenora. This measurement of fall in 1914 was, of course, made after the improvement of the channel east of Old Fort Island, and is probably greater than the fall would have been before that improvement. However, these notes substantiate, in general, the difference between Mill "A" and Wynn records.

The rise shown by the Public Works records during the latter part of June, 1906, cannot be accounted for.

The records of water levels above The Dalles indicate that between Keewatin tail water levels of 1038 and 1041, the fall between Keewatin and The Dalles varies from 1.4 to 1.75 feet. The elevations of high water marks indicate that at a tail water level of 1046.0

at Keewatin, the fall is 2.0 feet. The fall from Keewatin to The Dalles for a tail water level of 1043 should then be about 1.8 feet, while the fall from Keewatin to Kenora alone, according to the Public Works records, is 1.95 feet for July 10th, 1906. Acceptance of the Mill "A" tail water records for July 10th, would give a fall of 1.8 feet from Keewatin to The Dalles, and a fall of 1.05 feet from Kenora to The Dalles, which would be entirely reasonable for the condition of no flow through the Eastern Outlet. The Mill "A" records are therefore adopted through June, July, and August, 1906.

From August 22nd to September 20th, 1906, the Public Works and the Mill "A" records check very closely. The Wynn records, at Kenora, however, indicate some changes in location or immediate surroundings of Wynn's gauge between September 27th and 29th, as the fall previously shown between Keewatin and Kenora gradually reduces to zero in October.

During 1907 the line of mean tail water level at Keewatin follows the Mill "A" records without exception. The dip in the mean line during the first ten days of June is substantiated by the following note,—May 29, "A few (28) stop logs put in on 29 to 31 and about half (12) taken out again today". The dip between July 20th and August 10th also resulted from stop log manipulation, as indicated by the following note,—July 22nd, "Stop logs put in and driftwood north side cleared away, 15 to 20", and, Aug. 15, "22 stop logs taken out on south side". Additional stop logs were removed in September and October, causing the rise in tail water shown by the records. The Mill "A" records from August 21st, 1907, to the close of the year, are supported by the tail water levels taken at the Kenora Municipal Plant during that period.

During 1908, the line of mean tail water levels again follows the Mill "A" records quite closely, being supported, through most of the year, by the records of the Kenora Municipal Power Plant. The rise in tail water during the first ten days of March is justified by the following note, March 12, "Mill closed, 17 logs removed at dam 2nd to 7th". The Mill "A" tail water records for April 10th and May 14th are believed to be in error, because the Mill "A" fore bay records for the same dates also fail to agree with the other observed lake levels.

While no notes accompany the Public Works records for 1908 and 1909, there are notes in the Mill "A" records referring to manipulation of stop logs at the Norman Dam on most of the dates on which changes in tail water levels occur.

During 1909, except for the first two months, the Public Works records, the Mill "A" records, and the Kenora records, all agree very well, so that little difficulty is experienced in placing the line of mean tail water level at Keewatin. The Kenora records during April and

May, and again during November and December, lie somewhat above the Keewatin records. The tail water stage during 1909 averages between 1037 and 1038. This is the stage at which the fall from Keewatin to Kenora becomes zero, or may reverse, depending upon the relative rates of discharge through the West and the East Branches.

During this year, 1909, for practically the first time, the effect of closing down the mills on Sundays is reflected in the readings of the Public Works gauge at Keewatin, as for example, August 8th, 22nd, 29th, October 3rd, 10th, and 17th. The Kenora records also show the effect of reduced discharge on Sunday, as for example, June 6th, 13th, 20th, and 27th.

Throughout the year 1910, the line of mean tail water level at Keewatin again consistently follows the Mill "A" records. It also agrees with the Kenora records, except during November and December. The higher Kenora readings after November 3rd are due to the fact that the Kenora tail water gauge was moved from the pool below the plant to a point above the submerged weir which keeps the water level from dropping below about 1037, thus maintaining the vacuum in the draft tubes of the turbines during low water.

All rapid changes in tail water level during 1910 are accounted for by stop log manipulation at the Norman Dam. The effort to reduce leakage is indicated by the following note,—August 24 "Hansen at dam plugging up all leaks possible."

The records for 1911 are unsatisfactory. The Public Works records cannot be accepted during the winter of 1910 to 1911, because they show a sudden rise of exactly 1 foot between March 25th and 26th, without any apparent justification. Through the summer, the Public Works and Mill "A" records agree fairly well, and give a satisfactory mean tail water level. The gradual drop during the fall of 1911 may be accounted for, in a general way, by the following note which appears on August 23rd, 1911,—"Jas. Fraser started repairing dam at Norman on 23rd August." These repairs unquestionably resulted in a reduction in leakage through the dam, with the consequent drop shown in tail water level. The reduced leakage through the dam apparently also had its effect in arresting the drop in lake level, which had been in progress since the first of July.

The following records for September, 1911, were received from Mr. Scovil, of the Dominion Water Power Branch, Canada, too late for use on the graph.

Sept. 21, 1911, Tail water at Norman Dam	1035.43
Sept. 22, 1911, Water level in swift water of tail race, Mill "A"	1035.99
Sept. 22, 1911, Water level in river outside of tail race	1035.51

These records indicate a fall of 0.48 foot between swift water and the river below the tail race on September 22nd. As the stage de-

creases, this fall would increase, the discharge through the mill remaining the same. The fall has been taken as 1 foot in December, 1911, at a tail water stage of 1034.1, which is 1.4 feet lower than the stage above recorded, and the Department of Public Works records followed from the middle of October throughout the winter of 1911–1912.

In view of the fact that the Lake gradually rose during the winter and spring of 1912, the tail water level, due to increased leakage, should also rise. The Public Works records are therefore believed to be correct during the spring of 1912, and are used as the basis for the line of mean tail water level at Keewatin. The apparent discrepancies in the Mill "A" records are probably due to very low water. On June 25th, 1912, the Manitoba Hydrographic Survey established its Keewatin tail water gauge on the river bridge in the pool below Mill "A". During the same month, repairs were made at Mill "A", and the chain gauge, which had been read since 1896, was destroyed.

During June, 1912, an attempt was again made to stop the leakage through the Norman Dam. According to Mr. Scovil, of the Manitoba Hydrographic Survey, the stop logs were driven together with a pile driver, and the remaining leaks through the stop logs and the rock fill, closed, so far as possible, with straw mats, and sacks of manure. The work proved to be of a temporary character, and the leakage through the dam soon increased again.

The rising tail water stage from July to September, 1912, reflects both the rise in lake level and the increase in leakage through the Norman Dam.

From December, 1912, to March 10th, 1913, Manitoba Hydrographic Survey records are available only on the days of December 1, 2, 3, 7, 14, 21, 28; January 4, 11, 18, 25; and February 1, 8, and 15. For the intervening days between December 3rd, 1912, and March 10th, 1913, the Public Works records have been platted.

The improved character of the gauge records secured since the Manitoba Hydrographic Survey began reading its gauge is very apparent from the graphs. No difficulty whatever is experienced in drawing the line of mean tail water level at Keewatin from June, 1912, to December 31st, 1915. The effect of the closing down of the mills and power plants on Sunday is also very clearly shown in the tail water readings of these later years.

On account of the effect of the large expanse of water above White Dog Rapids, in absorbing sudden fluctuations in discharge by changes in storage over this large water area, such sudden changes in discharge do not immediately result in corresponding changes in tail water level at Keewatin. In consequence of this fact, the lowest gauge height at Keewatin usually occurs on Monday, even though the principal reduction in discharge, as the result of the shutting down of the mills and the reduction in load at the Kenora Power Plant, occurs

on Sunday. It appears that after the mills are shut down on Sunday, the stage in the pool below gradually falls, reaching its minimum on Monday, and then gradually rises again until about Wednesday or Thursday, when the true level, corresponding to the average work-day discharge, is established.

The line of mean tail water level at Keewatin, shown on the graphs, is drawn as closely as possible to correspond, throughout the week, to the average work-day discharge. In determining the Sunday values given in Table 70, "Daily Rate of Outflow—Lake of the Woods—All Outlets", the estimated or observed reduction in discharge through the Kenora Power Plant and the Keewatin mills, was deducted from the values taken off the rating curve of "Discharge through All Outlets". It is believed that in this way more accurate values of daily discharge were obtained than if these values of daily discharge had been determined directly from the daily gauge heights. If the latter method had been pursued, it is apparent that the value obtained for the Monday discharge would have been smaller than that obtained for the Sunday discharge, which is contrary to the actual facts.

This effect of reduced discharge on Sundays through the Power Plant, and through the Keewatin mills, is shown even as far back as 1894 and 1895, wherever accurate tail water records are available. The Monday readings, during these years, as at present, are usually lower than the readings for the preceding Sunday, as for example, September 17th and 24th, October 29th, and November 5th, 1894; and May 20th and 27th, June 3rd, July 8th, August 19th, 1895; and October 31st, 1898. Even though the effect of reduced Sunday discharge on the gauge heights on these dates is not as marked as in later years, it is none the less real.

HYDROGRAPHIC FEATURES OF OUTLETS AND OF WINNIPEG RIVER BELOW OUTLETS

In view of the fact that all of the recent discharge measurements taken by the Manitoba Hydrographic Survey have been referred to their Keewatin River Bridge gauge, and because any Keewatin gauge, as will be explained later, constitutes a good measure of the discharge of the Winnipeg River below the outlets of the Lake, it becomes desirable to deduce, from all available records, a mean tail water level *at Keewatin* for all the years for which any records are available, and then to use this mean tail water level for the purpose of computing the outflow from the Lake.

The recorded tail water levels, as was the case of the records of lake stage, are of varying degrees of accuracy, and considerable study was necessary in order to arrive at substantially correct values of tail water levels for the period of years under consideration.

In order to understand the method of arriving at a mean tail water level at Keewatin, and the factors that determine the relation between discharge through all outlets and gauge heights at Keewatin, it is necessary to be familiar, at least in a general way, with the more prominent hydrographic features relating to the outlets of the Lake, and to the Winnipeg River for some distance below. The "Key Plan of Outlets", Plate 19, based upon data furnished by the Manitoba Hydrographic Survey, shows the various outlets of the Lake and their interconnecting channels extending to a point on the Winnipeg River just below Old Fort Island. The "Sketch Map of Winnipeg River", Plate 20, based upon data secured, mainly, from the same source, shows a portion of the River below the outlets of the Lake.

From Old Fort Island, to a point about ten miles below, known as The Dalles, where the channel narrows down considerably, the Winnipeg River, except for two or three minor contractions, is virtually a lake with an area of about 20 square miles. Below The Dalles, the River widens out again, into what is also virtually a lake about 65 square miles in area. Some distance beyond Minaki, at a point 23 miles below The Dalles, the channel again narrows down, forming what is known as White Dog Rapids, where there is a total fall of about 43 feet.

About 4 miles west of The Dalles, there is an overflow channel known as Throat Rapids. Discharge measurements made during the fall of 1914 indicate that, for a total flow in the Winnipeg River of 13,506 c. f. s., only 534 c. f. s., or 4 per cent of the total flow, passed through Throat Rapids. Measurements made during May, 1915, indicate that, for a total flow in the Winnipeg River of 21,551 c. f. s., 2350 c. f. s., or 11 per cent of the total flow, passed through Throat Rapids.

For a discharge of 20,000 c. f. s. from all outlets of the Lake of the Woods, corresponding to a stage of 1041.35 at Keewatin, there is a fall of about 0.35 foot from the Keewatin mills to the contracted section of the channel at Old Fort Island; 0.6 foot fall at this control section; about 0.7 foot fall in the 10 miles from the pool below Old Fort Island to the head of The Dalles; 2.5 feet fall through The Dalles Rapids; and about 0.3 foot fall in the 23 miles of pool between The Dalles and White Dog Rapids. For a discharge of 10,000 c. f. s. from all outlets, corresponding to a stage of 1037.05 at Keewatin, there is a fall of about 0.15 foot from the Keewatin mills to the contracted section at Old Fort Island; about 0.5 foot fall at this control section; about 0.7 foot fall from the pool below Old Fort Island to the head of The Dalles; and about 1.4 foot fall through The Dalles. For a stage corresponding to the lower high water marks at Keewatin, at elevation 1046.50, equivalent to a discharge of 40,400 c. f. s., the lower water marks indicate a fall of 0.65 foot from the mills to the contracted

section at Old Fort Island; 0.55 foot fall at this control section; 0.8 foot fall from the pool below Old Fort Island to the head of The Dalles; and 4.2 feet fall through The Dalles. This information is also shown graphically on the "Profiles of Water Levels," Plates 21 and 22.

For varying rates of discharge, it will be observed, the fall opposite Old Fort Island remains very nearly constant at approximately 0.55 foot, while the fall from Keewatin to Old Fort Island varies from 0.1 foot at low stages to 0.65 foot at the highest stages, as indicated by the high water marks.

About 2 miles above Throat Rapids there is a contracted channel section through which there was a fall of 0.14 feet, at a stage of 1037.50, previous to the enlargement of the channel at Throat Rapids by the Department of Public Works, Canada, in 1907 and 1908. In April, 1913, there was a fall of .38 foot at these same rapids for practically the same water level, due to the enlargement of the Throat Rapids channel below. It is, therefore, apparent that the increased discharge capacity at Throat Rapids has resulted mainly in increased fall at the comparatively light rapids 2 miles above, rather than in a lowering of the entire pool above The Dalles. This pool could have hardly been lowered at all at low stages by the excavation at Throat Rapids, and it is probable that it is not lowered by more than 0.2 or 0.3 foot at the higher stages. Any small lowering of this pool which may have resulted from the channel improvement at Throat Rapids would be accompanied by a lesser lowering of the pool at Keewatin.

During 1912, the channel east of Old Fort Island was deepened, but as most of the excavated material seems to have been deposited in the river channel alongside of the cut, the effect of this change in channel would necessarily be very small at the higher river stages.

No other material changes appear to have occurred in the various channels below the outlets of the Lake of the Woods and above the ultimate control at White Dog Rapids during the period of years with which we are concerned.

POINTS OF TAIL WATER CONTROL

Plate 21 shows "Profiles of Water Levels" of the Winnipeg River from the outlets of the Lake to the pool between The Dalles and White Dog Rapids. It is evident that, during low stages, the ultimate control over the tail water level at Keewatin is exercised by the crest of the falls at White Dog Rapids.

The profiles on Plate 21 indicate that as the stage increases, control passes from White Dog Rapids, up stream, to The Dalles. This is evident from the rapid increase in fall at The Dalles from about 1.3 foot at low water to over 4 feet at high water. The next controlling section above The Dalles, although a minor one, is just below Old Fort Island, where most of the fall between Keewatin and The Dalles

PLATE U

"THROAT RAPIDS" CHANNEL OF WINNIPEG RIVER—1914

"THE DALLES" CHANNEL OF WINNIPEG RIVER—1914

occurs. Between the Old Fort Island control and The Dalles, there are two or three points at which appreciable current occurs, resulting in about 0.7 or 0.8 foot total fall in 10 miles for a discharge of 20,000 c. f. s. or more, and less fall for lower stages.

The flow in the channel above Old Fort Island, at Section 35, Plate 33, is sometimes in one direction and sometimes in the other, depending upon the relative rates of discharge from the various outlets of the Lake. It appears from Section 35, that under present conditions, at stages less than about 1035 at Keewatin, corresponding to a discharge of about 6800 c. f. s., there can be no flow through this section toward the East Branch. In case of high discharge through the Kenora Plant, however, water will overflow through this section into the West Branch.

The fall in the channel, from Keewatin to the Tunnel Island metering station (see Plate 22), varies from .05 foot at low stages to .43 foot at the highest stage for which we have Manitoba Hydrographic Survey meterings, namely, 1043.0 at Keewatin. When the discharge through the Kenora Power Plant is very small, and at a total discharge of about 13,000 c. f. s. from all outlets, the fall between the Keewatin gauge and the pool below the Kenora Power Plant, is about 0.7 foot.

During August and September, 1912, the Keewatin tail water gauge recorded elevations well below 1035.0 sea-level datum. During the days on which the Kenora Plant was operating under full load, the water level in the pool below the plant rose to an elevation of 1036.5, but on Sundays, when the plant was presumably operating under very light load, the water level fell to an elevation of about 1035.0. This indicates that the channel east of Old Fort Island, even after enlargement, still has insufficient discharge capacity to dispose of the water from the Kenora Plant at low stages, and that under those conditions the pool rises until a portion of the discharge passes through Section 35, Plate 33, into the West Branch. During high rates of discharge through the Norman Dam, and about 1000 to 1300 c. f. s. through the Kenora Plant, as in June, 1913, the flow undoubtedly was reversed. The stage at Keewatin at this time was 1041.3, and the fall between Keewatin and Kenora about 0.5 foot.

The only record of tail water levels at the Eastern Outlet previous to 1906 is that of July 29th, 1903, taken by Mr. G. M. Wynn, at Kenora, at the relatively high stage of 1043.0. This reading shows a fall of .7 foot from Keewatin to Kenora under those conditions, and would indicate a flow from the West Branch to the East Branch at that time.

Section 35, then, serves as an equalizing channel, tending to keep the pool above the controlling sections 31, 32, 33, and 37, at Old Fort Island, at approximately the same elevation for a given

total outflow from the Lake of the Woods, irrespective of the source of discharge, i. e., whether the outflow is through the Eastern, the Western, or the Keewatin outlets.

RATING CURVES OF OUTFLOW FROM LAKE OF THE WOODS

On Plate 69 is shown a rating curve of discharge for the West Branch of the Winnipeg River, based upon the measured discharge of the River at the Tunnel Island Metering Station of the Manitoba Hydrographic Survey, and the readings of the Keewatin River Bridge gauge reduced to sea-level datum. Only those discharge measurements which were made at a reasonably constant stage are selected as the basis for the curve. Those measurements which were made during a rising stage show a greater discharge, and those made during a falling stage show a lesser discharge than the gauge height would indicate. The discharge meaurements of Mr. H. G. Acres, Hydraulic Engineer of the Ontario Hydro-Electric Power Commission, made October, 1905, and the two measurements of Mr. J. C. Kennedy, made in 1892 and 1893, are also platted on this graph, to show their lack of agreement with the curve based on present conditions. The reason for this lack of agreement will be pointed out a little later.

On Plate 70 is shown a rating curve of discharge through all outlets of the Lake of the Woods. The readings of the Keewatin River Bridge gauge, reduced to sea-level datum, were platted against the sum of the discharges of the East and of the West Branch of the Winnipeg River. Only those measurements which were made at a reasonably constant stage were used as the basis for this curve. The measurements of Acres for all outlets and of Kennedy, after adding the estimated discharge through the Eastern Outlet, amounting to about 15 per cent of the total, are also platted, and fall well in line with an extension of the curve based on present conditions.

On Plate 71 are shown rating curves of discharge of the Winnipeg River at Keewatin, at The Dalles, and at White Dog Rapids. On this Plate the discharge measurements for only the last two curves are shown, as those for the first curve are shown on Plate 70, just discussed. These curves help in locating points of control at various stages. The measurements of flow at White Dog Rapids are much more consistent than those at Keewatin, because the gauge height in the pool above, at Minaki, is a true index to the discharge, and unaffected by sudden changes in outflow from the Lake of the Woods.

It is apparent, from these curves, that the ultimate point of control, at low stages, is White Dog Rapids, and at the higher stages is The Dalles, as previously stated.

It is interesting to note how well these rating curves pass through the high water marks found at Keewatin, above The Dalles, and above White Dog Rapids, when allowance is made for a runoff of about

0.8 c. f. s. per square mile from the local drainage area between Keewatin and White Dog. Pictures of these water marks are shown on Plate CC. As elsewhere stated, these water marks consist of the entire or partial absence of one or more species of lichens. The upper high water mark constitutes the lower limit of the dense growth of coarse, dark olive green—almost black—lichen (*genus gyrophora*). The second water mark constitutes the lower limit of the light green lichen (*genus parmelia*), among which are scattered a few small lichen of the coarse blackish variety. In a number of places another mark is quite evident, being the lower edge of a very small close growing black lichen. This mark, however, is not clearly discerned from the photographs.

EFFECT OF DISCHARGE THROUGH EASTERN OUTLET ON TAIL WATER LEVELS AT KEEWATIN

Before a rating of any one of the Keewatin tail water gauges can be accepted, it is necessary to determine the effect of variations in the relative discharges through the various outlets, on the readings of these gauges.

All of the water discharged from the Lake of the Woods must find its way through the several channels at Old Fort Island and into the pool below. It must also pass through the combined control sections at The Dalles and Throat Rapids. The stage of water above The Dalles, then, is an index to the total outflow from the Lake of the Woods. If Section 35, Plate 33, were closed entirely, changes in the discharge through the Eastern Outlet would still have an effect upon gauge heights at Keewatin by raising or lowering the water surface of the pool above The Dalles.

The effect of the discharge through the Eastern Outlet upon the Keewatin gauge is well illustrated by the location of the discharge measurement, made by Mr. H. G. Acres, Hydraulic Engineer of the Ontario Hydro-Electric Power Commission, in October, 1905, with respect to the rating curve of discharge, under present conditions, through the Western and Keewatin Outlets alone, Plate 69. The lake level in October, 1905, was 1061.5. This corresponds to an outflow through the Eastern Outlet, in a state of nature, of about 5150 c. f. s. The Keewatin tail water gauge at the time of Acres' measurement, in October, 1905, read 1043.8. This gauge height, reduced to 1043.7 because of falling tail water stage, corresponds to a discharge of 28,500 c. f. s. through all outlets, and to a discharge of 26,000 c. f. s. through the Western and Keewatin Outlets, according to our rating curve of the West Branch of the Winnipeg River, based on measurements of the Manitoba Hydrographic Survey under present conditions when about 500 to 1300 c. f. s. was discharged through the Kenora Plant on the Eastern Outlet.

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Acres' discharge measurement of 23,093 c. f. s., through the West Branch, when plotted, lies about 1 foot above the curve of discharge for the West Branch alone, whereas if his metered flow of 5321 c. f. s., through the Eastern Outlet, is added, the total, 28,414 c. f. s., falls practically on our curve of total outflow, Plate 70.

Kennedy's two measurements of discharge of the West Branch of the Winnipeg River, in the early nineties, show the same lack of agreement with the rating curve of outflow through the West Branch alone, as does Acres' measurement. However, when the flow through the Eastern Outlet, and the estimated flow through the mills and the Kenora Power Plant (which latter constitutes but a small percentage of the total flow), is added to Kennedy's measured flow through the West Branch, the totals thus obtained, dating back to 1892 and 1893, fall very well in line with the rating curve of "Discharge through all Outlets," Plate 70, which we have derived from recent discharge measurements, and passing, as was just remarked, through Acres' measurement of 1905.

The data entering into the total outflow on the two dates of Kennedy's measurements follow:

Discharge measurement of November 11th, 1892

	c. f. s.
Measured Discharge—West Branch (Reduced 5% as per Kennedy's request)	22560
Estimated Discharge—Keewatin Lumber & Mfg. Co	150
Estimated Discharge—Mill "A"	350
Total Discharge—At Tunnel Island Gauging Station	23060
Discharge through Eastern Outlet (Value taken from rating table for lake stage of 1060.25)	3900
Discharge through Kenora Plant at Eastern Outlet	90
Total discharge through all outlets	27050

This discharge corresponds to a gauge height of 1043.1 at Keewatin, derived from the observed gauge height of 1043.3 at Norman, by correcting for falling stage and for relation of gauge readings at Norman and at Keewatin.

Discharge measurement of May 26th, 1893

	c. f. s.
Measured Discharge—West Branch (Reduced 5% as per Kennedy's request)	15935
Estimated Discharge—Keewatin Lumber & Mfg. Co	400
Estimated Discharge—Mill "A"	350
Total discharge—At Tunnel Island Gauging Station	16685
Discharge through Eastern Outlet (Value from rating table for lake stage of 1059.25)	3190
Discharge through Kenora Plant at Eastern Outlet	60
Total discharge through all outlets	19935

This discharge corresponds to a gauge height of 1041.4 at Keewatin, derived from the observed gauge height of 1041.4 at Norman by correcting for rising stage and for relation of gauge readings at Norman and at Keewatin, which corrections, in this instance, just balance.

If the discharge through the Eastern Outlet, particularly at high stages, did not raise the Keewatin gauge an amount corresponding practically to the full discharge, the measurements of Kennedy and of Acres should agree with the rating curve of "Discharge through Western and Keewatin Outlets" instead of with the rating curve of "Discharge through all Outlets."

Still further evidence, in addition to that already adduced, is available, to show that Keewatin gauge heights constitute a substantially correct measure of the discharge through all outlets of the Lake of the Woods, mainly because the principal control at the higher stages is at The Dalles, and any change in discharge from the Lake into the pool above The Dalles will raise or lower the pool at Keewatin by an amount corresponding almost exactly to the change in discharge. The effect of possible changes in the runoff from the local drainage area between The Dalles and Keewatin, is negligible.

In May, 1906, preparations were made for the construction of the present Kenora Municipal Power Plant. A cofferdam, shutting off all flow through the Eastern Outlet, was begun in May, and completed about June 15th of the same year. The graph of observed tail water levels for 1906, Plate 61, shows that from May 10th to June 20th the tail water level at Keewatin fell from 1044.2 to 1042.6. The notes which accompany the gauge readings make no mention of any change in the stop logs at the Norman Dam. The only note indicating any change, whatever, is that which refers to the accumulation of some driftwood at the dam. In view of this fact, it is clear that the fall in tail water level at Keewatin was due primarily to the closing off of the Eastern Outlet. The flow through the Eastern Outlet, in a state of nature, prior to the construction of the cofferdam in May, 1906, and for the lake stage of about 1061.3 prevailing at that time, was about 5000 c. f. s. The fall in Keewatin tail water, according to the rating curve of "Discharge through all Outlets," corresponds to a *reduction* in discharge of 6260 c. f. s. Taking, now, the probable reduction in outflow, which might correspond to the accumulation of driftwood at the Norman Dam previously noted, and, also, some reduction due to the possible closing of mills, and adding these to the reduction in flow through the Eastern Outlet resulting from the construction of the cofferdam, we obtain a total reduction in discharge practically equal to that represented by the fall in tail water level at Keewatin.

Even though the variations in the discharge through the Kenora Plant on the Eastern Outlet, during the past two years, have been

very small, yet the effect of discharge through the Eastern Outlet on the gauge height at Keewatin is reflected, to some extent at least, in the discharge measurements of these years. For instance, the mean departure of the measurements of discharge through the West Branch, from the rating curve of discharge for the West Branch alone, is slightly greater than the mean departure of the measurements of discharge from all outlets from the rating curve of discharge through all outlets. If the Kenora Plant had discharged a larger percentage of the total flow, the difference in favor of the rating curve of discharge through all outlets would have been considerably greater.

Although the variation in discharge through the Kenora Plant was only from about 600 to 1300 c. f. s., which represents only about twice the probable error in the discharge measurements, yet this small variation was, in a measure, reflected in the gauge height at Keewatin. Discharge measurements, made when the Kenora Plant was discharging in the neighborhood of 600 c. f. s., indicated, on the whole, a slightly lower gauge height than when the plant discharged 1300 c. f. s., with the outflow through the West Branch remaining the same.

RELATION BETWEEN DISCHARGE THROUGH VARIOUS OUTLETS AND TAIL WATER LEVELS AT KEEWATIN

On Plates 72 to 75 are presented data which further emphasize the intimate relationship which exists between discharge through any one of the outlets of the Lake of the Woods and tail water levels at Keewatin. These data also show the extent to which manifestations of change in stage of the Winnipeg River, as represented by gauge heights at Keewatin, lag behind changes in discharge of the River as obtained from such meter measurements, as have been taken whenever rapid changes occurred in outflow from the Lake, due to the manipulation of the Norman Dam, or to the complete or partial closing down of the Keewatin mills or the Kenora Power Plant. This lagging of changes in stage behind changes in discharge is due to the large storage afforded by the pools below the outlets of the Lake, as may be seen by reference to the Sketch Map of the Winnipeg River, Plate 20.

The data of these Plates 72 to 75 clearly show:

1st. That changes in the discharge through Mills "A" and "C" result in changes in the tail water level at Keewatin;

2nd. That changes in the discharge through the Kenora Power Plant are also reflected in the readings of the Keewatin tail water gauges;

3rd. That the effect of changes in discharge through the Kenora Power Plant on water levels at Keewatin is less than the effect of

changes in the discharge through the Keewatin mills for the period for which data are shown on these plates, primarily, because of the fact that the extreme variation in the daily discharge through the Kenora Power Plant is from about 600 c. f. s. to 1300 c. f. s., or only about 700 c. f. s., whereas the extreme variation in the daily discharge through the Keewatin mills is from about 100 c. f. s. to 1500 c. f. s., or about twice the variation which occurred in the discharge through the Kenora Plant during the period covered by the data of Plates 72 to 75;

4th. That discharge measurements made during a rapidly rising stage of the River, when reduced to the corresponding tail water level at Keewatin, invariably represent water levels considerably higher than those recorded by the gauge;

5th. That discharge measurements made during a rapidly falling stage of the River, when reduced to the corresponding tail water level at Keewatin, invariably represent water levels considerably lower than those recorded by the gauge.

The conclusions to be drawn from the above facts are:

1st. That in determining daily discharge it is necessary to correct the mean observed tail water level, during rapidly rising or falling river stages resulting from the manipulation of the Norman Dam, for the retarding effect of the pool below the outlets, and then to take, from the rating table, values of discharge corresponding to the *corrected* gauge heights instead of to the *observed* gauge heights;

2nd. That daily discharge values, if computed from the daily tail water levels at Keewatin, would show a less discharge on Monday than on Sunday, because of the before mentioned pool effect. The Monday discharge, as a matter of fact, is more than the Sunday discharge, and, therefore, the closest approximation to the actual discharge may be ascertained by using, throughout the whole week, a work-day discharge corresponding to the gauge heights recorded during the latter part of the week when a condition of equilibrium has become established between stage and discharge, and then to deduct a specific amount for the reduced discharge on Sundays;

3rd. That tail water levels at Keewatin are a measure of the total discharge through all outlets of the Lake of the Woods, including that through the Kenora Municipal Power Plant, previously discussed.

Consideration has been given to the possibility of employing a rating curve of discharge for the West Branch, alone, of the Winnipeg River, at the Tunnel Island metering station.

To discharges determined from such a rating curve by means of the observed tail water levels at Keewatin, would be added the discharge through the East Branch. Now, so long as the amount of discharge through the East Branch varied only within the limits

prevailing during the more recent period for which discharge measurements have actually been made in the West Branch, values of discharge determined by the above method would be substantially correct. It will be recognized, however, that if applied under the great variety of conditions obtaining on the East Branch, during past years, the adoption of such a method would give a total discharge substantially in error. Virtually, an allowance for the discharge through the East Branch would twice be introduced into the total. It will be perceived, therefore, that while the error resulting from a determination of the total daily discharge in this manner would be relatively small for present changes in discharge through the East Branch, it would, however, rapidly increase with increased discharge through this Branch, and would consequently be very substantial during the period preceding the construction of the present Kenora Power Plant.

Since accurate records of the daily discharge through Mills "A" and "C", previous to May, 1913, are not available, the data on Plates 72 to 75 are not quite as complete as might be desired.

During the summer of 1912 both the Norman Dam and Mill "A" were closed. The closing down of Mill "C" and of the Kenora Plant over Sunday, in August 1912, as shown on Plate 72, is followed by a lowering of about .3 foot in tail water level at the Manitoba Hydrographic Survey river gauge at Keewatin. During the latter part of September, when the discharge through the Kenora Plant was very uniform, the change in stage due to Sunday reductions in discharge was reduced to about half this amount. The change shown by the gauge presumably represents the change in the discharge through Mill "C". The pool effect is clearly emphasized by the fact that the change in gauge reading occurs on the day following the change in discharge.

In October, 1912, the Norman Dam was partly opened, but it is apparent that the changes in stage lag several days behind the changes in discharge. The effect of changes in discharge, due to partial Sunday closing down of the Kenora Plant and Mill "C", is just as apparent, however, at the October stage of 1037.0 as they were at the August stage of 1034.0.

The reduction in average discharge through the Kenora Plant, during the first half of April, 1913, coupled with the closing down of one of the mills from March 25th to 30th, shown on Plate 72, is reflected in the gauge readings, as is also the effect of Sunday reductions in discharge.

The data on Plate 73, particularly for July 21st to 23rd, again manifest the effect, on the tail water levels at Keewatin, of a reduction in the discharge through the Kenora Plant. During the latter part of August and the first part of September, while the Kenora

Plant was discharging uniformly throughout the week, the Sunday effects from the mills are also much less than they are when the discharge through the Kenora Plant was also considerably reduced on Sundays, as in July and October.

The effect of the pool in holding up the stage during rapid reductions in discharge is also distinctly shown in July and in October, 1913, on this plate.

The data on Plate 74 for the first half of 1914 again show the effect of Sunday reductions in discharge through the mills and the Kenora Plant, and also the lagging of stage behind discharge on increasing stage.

The data on Plate 75, for August to November 1914, show the same effects. The absence of sharp drops in stage during the relatively uniform discharge from Mills "A" and "C" and the Kenora Plant, between August 29th and September 12th, is distinctly noticeable.

The effect of the increased discharge through the Kenora Plant, in holding up the stage on August 20th, 21st, and 22nd, and the opposite effect of reduced discharge through Mills "A" and "C" between November 2nd and 7th, shown on this plate, are also worthy of note.

DISCHARGE THROUGH EASTERN OUTLET

From all information, at present available, it appears that until the year 1892, when the first power house was constructed, the Eastern Outlet of the Lake of the Woods remained in its natural condition. A photograph taken in 1881, of the natural falls at the Eastern Outlet, is reproduced on Plate V. The falls were formed by a rock ledge extending across the channel between rocky banks about 65 feet apart at high water. The distance, from what may be termed the Lake proper, to the site of the falls is approximately 1400 feet. In a state of nature, very little fall existed in this channel between the Lake and the crest of the falls. This is shown by photographs and substantiated by testimony.*

A map of the Eastern Outlet is shown on Plate 23. A profile along the channel is shown on Plate 24. Cross sections of the channel are shown on Plate 28. The fall in a state of nature was about 17 feet.

The first power house, was a wooden structure, as shown by photographs reproduced on Plate W. These views, when considered together with the plans of the present power house, and cross sections taken of the unwatered channel at the time of plant

* From Progress Report of the International Joint Commission, Lake of the Woods Levels, p. 140.
Question by Commissioner Powell at Kenora Hearing, Sept. 20, 1912: "Was there any descent in the river so far as your idea goes, from the immediate outlet down to the present site of the dam?"
Answer by Mr. D. J. Mather: "Nothing more than what would make a current of four or five miles an hour. It toppled right over like if it toppled over the edge of this table."

construction in 1906, indicate that the upper part of the head race was originally made by excavation into the natural bank, and that consequently the discharge of the natural outlet was not substantially altered,—except in so far as the total discharge was increased above the natural discharge by a varying amount consisting of the flow through the power house.

A head race, stated to have been some 10 feet in width and approximately 10 feet in depth below the high water mark, which appeared in the channel, and commencing slightly above the crest of the falls, was constructed partly in rock excavation and partly in timber structure along the easterly or right bank of the channel.

The original turbine installation, in 1892, consisted of one 66″ Leffel Special Vertical turbine. This wheel has a catalog (1897) rating of 279 H. P. under 17′ head, running at 85 R. P. M., and using 173 c. f. s. at full gate opening.

The first power plant, owned by the Citizens Telephone & Electric Light Company, was put in operation late in the fall of 1892, but in the following year a change was made in the penstock and the original turbine was moved. About the year 1894 the head race was enlarged toward shore by rock excavation to a width of 20 feet, and a second turbine installed. This latter wheel was a 66″ Leffel Standard Capacity Vertical Turbine, rated at 245 H. P. under 17′ head, when running at 85 R. P. M., and using 152 c. f. s. at full gate opening. No change is stated to have occurred in the plant during 1895, but in 1897 a third turbine was installed. This wheel was a 62″ vertical style turbine of the "Boss" type, manufactured by William Hamilton Manufacturing Company, and having a rating of 291 H. P. when running at 80 R. P. M. and using 189 c. f. s. at full gate opening under 17′ head.

In May, 1906, construction of the present Kenora Municipal Plant was commenced. Between May and June, cofferdams were constructed and the portion of the river bed adjacent to the crest of the falls unwatered. The old power house was demolished. The outer head race wall and a portion of the channel bed were removed, thus making head race and river into one channel of practically uniform depth.

The profile and sections of the Eastern Outlet shown on Plates 24 and 28 were prepared from the survey made by the Manitoba Hydrographic Survey in 1913. The original crest of the falls was approximately at Section 8, as shown on the "Map of the Eastern Outlet," Plate 23, and on the profile of the Eastern Outlet, Plate 24. The section at the crest of the Falls, in a state of nature, as given on Section 8, Plate 28, was derived from a cross section, dated June 23, 1906, made by Mr. G. M. Wynn, Resident Engineer during the construction of the power plant, and stated to have been very slightly below the crest of the falls. The old head race is shown in dotted

PLATE V

KAH-KAH-KEE-WITCH-E-WAN FALLS ON EASTERN OUTLET—PRIOR TO 1881

EASTERN OUTLET PRIOR TO CONSTRUCTION OF PRESENT PLANT

Courtesy of Mr. G. M. Wynn

KENORA POWER PLANT AND FALLS ON EASTERN OUTLET

Courtesy of Mr. H. Rideout

ORIGINAL KENORA MUNICIPAL PLANT—HEAD RACE BEING WIDENED

PLATE X

Courtesy of Messrs. T. Pringle & Son

UPPER COFFERDAM ON EASTERN OUTLET—1906

Courtesy of Messrs. T. Pringle & Son

LOWER COFFERDAM ON EASTERN OUTLET—1906

lines on this section. The section, as furnished by Mr. Wynn, clearly shows the old head race to have been in rock excavation, and to have been approximately 20 feet wide. This excavation for the head race left a ridge, approximately 4 feet high above the bottom of the head race, lying between the head race and the river channel. By extending the channel side of this ridge upward to connect with the present natural bank, we have derived the estimated original profile of Section 8.

The channel elevations of the recent survey made by the Manitoba Hydrographic Survey, indicate that for a length of approximately 90 feet measured back from the crest of the original falls, the rock ledge was blasted out from the shore side of the old head race to the opposite bank, thus giving, at this point, a bottom elevation of 1044.0, and a width of approximately 85 feet. The data of this survey indicate that, at the present time, the ridge at Section 5 is the ultimate control of flow through the Eastern Outlet at low stages. Mr. Wynn has stated, that, upon completion of the power plant, a portion of the upper cofferdam, located approximately at Section 5, was removed by dynamite and the material scattered in the channel. A cross section by Mr. Wynn stated to have been taken forty feet below the upper cofferdam, gives a uniform elevation of 1047.0 over a considerable width of the channel bed. The conclusion, then, is that such a point of control as is indicated by Section 5 *did not exist in a state of nature.*

The discharge through the Eastern Outlet, in a state of nature, varied, of course, with the stage of the Lake and approximated the discharge over a weir whose length is equal to the width of the channel at the falls and whose crest is at the same elevation as the crest of the falls. The area of the cross section at the crest of the falls varied from 738 square feet below elevation 1063 sea-level datum, to 156 square feet below elevation 1053. The effective weir depth at elevation 1063 is estimated at 14 feet, which gives a mean width of cross section of 52.7 feet. The effective depth at elevation 1053 is estimated as 4 feet, which corresponds to a mean width of 39 feet.

Only three measurements of the discharge through the Eastern Outlet, prior to 1912, are on record. These are as follows:

July 29, 1903, by Pringle & Sons, discharge	4122 c. f. s.
October 14th, 1905, by Acres of the Ontario Hydro Electric Power Commission, discharge	5321 c. f. s.
April 8th, 1906, by Acres of the Ontario Hydro Electric Power Commission, discharge	4490 c. f. s.

The above records give the total discharge through the Eastern Outlet, including the flow through the power house. In order to ascertain the discharge through the natural outlet alone, it is necessary to deduct the discharge through the power house. This may

be estimated on the basis of turbine capacity and load carried by the plant at the times the discharge measurements were, respectively, made.

The maximum rated discharge capacity of the turbine installation in use between 1897 and 1906, was 514 c. f. s. under a 17 foot head. As no additional turbines were installed until 1907, it is probable that in 1903 the plant was never operated at quite its maximum capacity. The peak load discharge for 1903, occurring presumably in December, has been estimated as 450 c. f. s. If we assume that the load carried by the plant in 1903 was similar to that carried at the present time, the relation between maximum load during the year, and probable load during any given month of the year, can be estimated. We know the daily load factor under present conditions, and assuming that this has increased somewhat during recent years, it is possible to estimate the approximate amount of water used by the power plant during the day, for those particular days on which the meter measurements were made.

On this basis the July peak load would represent a discharge of about 225 c. f. s., and the day load at the time of the metering on July 29, 1903, would represent a discharge of about 80 c. f. s. Deducting this flow through the power house from the total measured discharge gives 4042 c. f. s. as the flow through the Eastern Outlet, in a state of nature, for a lake stage of 1060.57 sea-level datum.

In a similar manner the flow through the power house on October 14th, 1905, has been estimated as 115 c. f. s., thus leaving 5206 c. f. s. flowing through the Eastern Outlet at a lake stage of 1061.52. Similarly, the flow through the Eastern Outlet, on April 8th, 1906, is found to have been 4370 c. f. s. at a lake stage of 1060.70.

With the ridge at the crest of the falls acting as a weir, the outflow (Q) through the Eastern Channel in a state of nature is represented, approximately, by the formula,—$Q = c\,l\,h^{\frac{3}{2}}$, where

c=a coefficient depending on the character of the weir and the depth of the water flowing over it.

l=the length of the weir in feet.

h=the head on the weir in feet measured in quiet water some distance back from the weir.

The values of the coefficient "c," as determined from the above discharge measurements, together with the stage of the Lake at the time the several measurements were taken, are given in the following table:

Date	Discharge c. f. s.	Lake Stage Sea-level Datum	C
July 29, 1903	4042	1060.57	2.07
Oct. 14, 1905	5206	1061.52	2.31
Apr. 8, 1906	4370	1060.70	2.17

PLATE Y

Courtesy of Messrs. T. Pringle & Son

UNWATERED CHANNEL OF EASTERN OUTLET DURING CONSTRUCTION OF PRESENT KENORA MUNICIPAL PLANT—1906

REMAINS OF LOWER COFFERDAM AND SUBMERGED WEIR NOW USED TO SEAL DRAFT TUBES

PLATE Z

EASTERN OUTLET—LAKE OF THE WOODS—1913

PRESENT KENORA MUNICIPAL PLANT ON EASTERN OUTLET

These values for the coefficient "c" are approximately 80% of those for a wide crested weir, as determined by laboratory experiments. Sufficient explanation for this difference, however, would appear to be found in the fact that the river bed was rough and that there were necessarily a good many eddy currents.

A curve was constructed by plotting the above values of "c" against lake stages. This curve, when extended, gives "c" equal to 1.9 for a lake level of 1054 or less, increasing up to 2.6 for a lake level of 1063. These values agree approximately with the accepted variation of the coefficient with changes in depth on the crest of a broad crested weir. By using the discharges computed from the weir formula by means of the above constants, and with the three actual meterings as a basis, the "Rating Curve of Discharge through Eastern Outlet—Lake of the Woods—in State of Nature," as given on Plate 68, was derived.

The cofferdams built in May and June, 1906, entirely shut off the flow over the falls. Since the new plant commenced operation on February 9th, 1907, the flow at the Eastern Outlet has been through the power plant. The computed values of such flow have been furnished by the Manitoba Hydrographic Survey, and are available for the period since August, 1907.

The energy being developed at the present Kenora Municipal Plant is being used for lighting, for water supply, and for manufacturing purposes. The plant was constructed for a total installation of six units. The preliminary installation comprised only three units, each unit consisting of four 40″ Improved Samson runners on a horizontal shaft, direct connected to a 625 k. w., 2400 volt, 60 cycle, 3 phase generator. The installation also included two 120 volt, 1460 ampere, D. C. exciters, each connected to a 30″ Twin Runner Horizontal Samson turbine. In March, 1913, a fourth unit manufactured by the Allis Chalmers Bullock Co. of similar capacity to the earlier units was installed.

In the construction of the present power house and the establishment of gauges at the Plant, an assumed datum of 100.00 was used, which practically coincides with Kennedy's High Water Mark on Tunnel Island, elevation 102.54, Kennedy's datum.

From February to April, 1913, meter measurements were taken at Section 7, Plate 28, by the Manitoba Hydrographic Survey. Readings of fore bay and tail race gauges, together with load carried and gate openings, were made while the meter measurements were in progress. The efficiency of the power plant from input to output was calculated for each discharge measurement. These efficiencies were then grouped according to load. The average load and efficiency of each group was next obtained and from the results a load-efficiency curve was plotted. From this curve, load-dis-

charge curves were calculated and then plotted for heads of from 18 to 22 feet. These latter curves were used by the Manitoba Hydrographic Survey in estimating the daily discharge at this outlet since August 21st, 1907, at which date the recording of loads was commenced at the power house.

Typical daily load curves for the Kenora Plant are shown on Plate 38 and a summary of the monthly average head, load and estimated discharge from August, 1907, to December, 1914, inclusive, appears in Table 89.

DISCHARGE THROUGH MILL "A"—LAKE OF THE WOODS MILLING COMPANY

The Lake of the Woods Milling Company's Mill "A" is located at Keewatin at the westerly end of a narrow rock ridge separating Portage Bay, Lake of the Woods, from Darlington Bay, an arm of the Winnipeg River. Under natural conditions there was no connection between the Lake and the River at this site, but in the year 1887 a cut was made through the rock ridge by the Lake of the Woods Milling Company and a power house was constructed at the lower end at Darlington Bay. The location of the power house, mill and cut is shown on the Key Plan of Outlets, Plate 19, and various selected cross sections of the head race are given on Plate 34. Photographs of both Mills "A" and "C" are shown on Plate AA.

For approximately 350 feet above the power house the canal or head race was constructed partially in rock excavation and partially in timber structure, the north flume wall being composed of rock-filled timber cribs. During the year 1912 this timber wall was replaced by one of concrete.

The power developed at this site has been utilized in the manufacture of flour. The mill has been continuously in operation since construction, with the exception of some temporary shut downs for repairs or for the installation of new machinery. The plant is operated a full day of 24 hours, but, except for the fire pump, is closed on Sundays. This pump is kept in continuous operation.

The turbines installed at the plant are listed below. Two are direct connected to generators, the electric power being used for the lighting of Mills "A" and "C" and for the operation of hoists, elevators, etc., in both mills. With the exception of the electric power transmitted to Mill "C" all power developed at this site is used in Mill "A."

The turbine installation from 1887 to date has been as follows:

1887. 2–60″ "Standard New American" turbines manufactured by the Dayton Globe Iron Works were installed. The manufacturers' full gate discharge rating for each 60″ wheel under 20 foot head, is 209 c. f. s.

1888. 1–22″ "Standard New American" turbine, manufactured by the Dayton Globe Iron Works was installed. This wheel was used in the generation of elec-

MILL "A" MILL "C"

TWO VIEWS OF THE KEEWATIN MILLS

PLATE AA

tric power for the lighting of the plant. The manufacturers' full gate discharge rating for this wheel under 20 foot head is 28 c. f. s.

1896. 1–60″ turbine was *removed*.

2–66″ "Standard New American" turbines of the Dayton Globe Iron Works were installed. The manufacturers' full gate discharge rating for each 66″ wheel under 20 foot head is 267 c. f. s.

1905. March and April, 2 units of 33″ twin runner horizontal, "Special New American" turbines, manufactured by Wm. Kennedy & Sons, Owen Sound, Ont., were installed. Each unit was direct-connected to a 240 K. W. D. C. Generator, manufactured by the Canadian General Electric Company. The manufacturers' full gate discharge rating for each unit under 20 foot head is 196 c. f. s.

1–33″ single runner horizontal "Special New American" turbine, manufactured by Wm. Kennedy & Sons, Owen Sound, Ont., direct-connected to a fire pump was installed. The manufacturers' full gate discharge rating for this wheel under 20 foot head is 98 c. f. s.

1912. The remaining 60″ and the two 66″ "New American" turbines were removed. One horizontal unit, consisting of two pairs of 60″ runners, manufactured by J. M. Voith & Co., was installed.

The present installation together with the manufacturers' rating based on a 20 foot head is, therefore, as follows:

One unit consisting of 2 pairs of 60″ runners, rated at 2400 H. P. and connected by rope drive to the mill.

One unit consisting of a single 22″ vertical turbine, rated at 95 H. P., for the operation of the machine shop.

Two units each consisting of a pair of 33″ runners, each unit rated at 360 H. P. and direct-connected to a 240 K. W. D. C. Generator.

One unit consisting of a single 33″ horizontal turbine, rated at 180 H. P. connected to a fire pump.

The only available record of discharge through the flumes of Mill "A" made previous to 1912 is a meter measurement of 899 c. f. s. made by Mr. H. G. Acres for the Ontario Hydro-Electric Power Commission on October 16th, 1905. Since 1912 frequent discharge measurements have been made by the Manitoba Hydrographic Survey. The results of these measurements are summarized in Table 55. On the basis of these discharge measurements and the records of gate openings, load, etc., the daily discharge through Mill "A" from May, 1913, to December, 1915, inclusive, has been estimated by the Manitoba Hydrographic Survey, and appears in Table 71.

It is necessary, however, to make some estimate of the probable water consumption at Mill "A" previous to 1912. The discharge measurements made since 1912 indicate that on work-days an average of about 650 c. f. s. was used for the mill drive at Mill "A;" 20 c. f. s. for the fire pump; and 180 c. f. s. for the hydro-electric units generating energy for lighting and for miscellaneous power requirements in both Mill "A" and Mill "C." The total work-day discharge through Mill "A" since 1912 has ranged between 700 and 1,000 c. f. s. as shown in Table 71.

The record of 899 c. f. s. obtained by the Ontario Hydro-Electric Power Commission in October, 1905, consequently indicates approximately the same water consumption at Mill "A" in 1905, as at the present time.

As the total rated full gate discharge capacity of the wheels used for the mill drive between 1896 and 1912 was 743 c. f. s. an average work-day discharge of 650 c. f. s. has been adopted by us for the mill drive for the entire period from 1896 to date.

The total rated full gate discharge capacity of the wheels used for the mill drive from 1888 to 1896 was 418 c. f. s. or 56% of that used from 1896 to 1912, consequently, we have assumed that the average work-day discharge for the mill drive of Mill "A" from 1888 to June 30, 1896 has been about 350 c. f. s.

From May 1st, 1905 (the date of installation of the present lighting plant and fire pump), to May, 1913 (when daily discharge estimates were first made for Mills "A" and "C"), an average total work-day discharge of 850 c. f. s. has been adopted, consisting of 650 c. f. s. for the mill drive, 20 c. f. s. for the fire pump and 180 c. f. s. for the two generator units.

The following table summarizes our conclusions with respect to the daily discharge through Mill "A" previous to May, 1913.

Estimate of daily discharge—Mill "A"

Period	Average workday discharge cu. ft. per second.
1888 to June, 1896, inclusive	350
July, 1896, to April, 1905, inclusive	650
May, 1905, to April, 1913, inclusive	850

A further inspection of the estimates of daily discharge given in Tables 71 and 72 indicates that at times both Mill "A" and Mill "C" have been operated over Sunday; that at other times they have been closed at midnight on Saturday and started again at 7.00 a. m. on Monday; and that at still other times they have been closed at 6.00 a. m. on Sunday and started again at 7.00 a. m. on Monday. In the absence of more definite information, we have assumed that previous to May, 1913, both Mills were shut down for twenty-four hours on Sunday of each week, whether that shut down occurred from midnight on Saturday to midnight on Sunday or from 6.00 a. m. on Sunday to 7.00 a. m. on Monday.

The estimates of daily discharge through the mills are required, mainly, because as previously stated, the method we have adopted for ascertaining the discharge from the Lake on the basis of observed

tail water levels at Keewatin, requires that an allowance in discharge be made in order to compensate for the reduction in flow due to the Sunday closing down of the mills.

DISCHARGE THROUGH MILL "C"—LAKE OF THE WOODS MILLING COMPANY

The Lake of the Woods Milling Company's Mill "C" is located at Keewatin at the easterly end of the rock ridge separating Portage Bay, Lake of the Woods, from Darlington Bay, an arm of the Winnipeg River. There was no natural outlet at this site, but about the year 1881 a small cut was made through the rock ridge by Wm. McAuley and power developed for the operation of a saw mill. This mill is stated to have been first operated in the year 1882. In the same year the site became the property of Messrs. Dick and Banning and continued to be used for the same purpose until the year 1893. From that year until the year 1899, the plant was shut down and the flume closed. Power was again developed during the years 1899 and 1900 by the Ottawa Gold Mining and Reduction Company, but in the latter part of 1900 the flume was again closed and remained in that condition until the year 1905. During this year the site was acquired by the Keewatin Flour Milling Company, and the flume is stated to have been approximately doubled in size. Before the completion of the plant, the Keewatin Flour Milling Company was purchased by the Lake of the Woods Milling Company, and it was not until May, 1907, that the present mill, known as Mill "C", was put in operation. From the year 1900 to 1907 no water was discharged through this outlet, but from 1907 to date, with the exception of temporary shut-downs for repairs, the mill has been in continuous operation. The location of the power house and intake is shown on the Key Plan of Outlets, Plate 19, and various selected cross sections of the head race are given on Plate 34.

Since this site was acquired by the Lake of the Woods Milling Company, the power has been used in the manufacture of flour in Mill "C".

No information has been obtained regarding the turbine installation in the earlier power house located at this site. The following turbines have constituted the installation since the site was acquired by the Lake of the Woods Milling Company:

2–56″ twin runner horizontal turbines manufactured by Wm. Hamilton Company. The manufacturers' full gate rating for each unit under a 20 foot head is 900 H. P.

1–45″ twin runner horizontal turbine manufactured by Wm. Hamilton Company. The manufacturers' full gate rating for this unit under a 20 foot head is 600 H. P. This turbine is direct-connected to a 275 K. W. generator but is used only in case of a break-down in the hydro-electric equipment at Mill "A".

No record has been obtained of any discharge measurements made previous to the year 1912. On July 17th, 1912, a gauging station was established, by the Manitoba Hydrographic Survey, at the intake to the mill.

The discharge measurements made at this station from 1912 to 1915 are given in Table 56. On the basis of these measurements and the records of gate openings, etc., the daily discharge through Mill "C" from May, 1913, to December, 1915, inclusive, has been estimated by the Manitoba Hydrographic Survey, and appears in Table 72.

These estimates indicate that during 1913 and 1914 the average work-day discharge through Mill "C" has been about 700 c. f. s. As the turbine installation at Mill "C" has not been changed since the beginning of operation on May 1st, 1907, we have adopted a value of 700 c. f. s. as the average work-day discharge from that date until May, 1913. Since the latter date daily discharge estimates have been made by the Manitoba Hydrographic Survey.

DISCHARGE THROUGH KEEWATIN LUMBER & MANUFACTURING COMPANY'S PLANT

The power site which is situated at the extreme westerly end of Portage Bay, Keewatin, is known locally as the Keewatin Lumber and Manufacturing Company power site, this company having been the owners and users of the site while the plant was in operation. The depression where the head gates of the plant were later located is stated to have acted as an overflow channel for the Lake of the Woods, at high stages.

Construction of the power house and head race was commenced in 1879, and the mill is stated to have been put in operation in June, 1880. The head race was constructed partially in earth and rock excavation and partially in timber structure. In, or about, the year 1885, the intake at Keewatin or Portage Bay was further deepened by the use of a log drag, by means of which the muskeg or soil was loosened and was then carried away by the current through the head race.

The power developed at this site was used for the operation of a saw mill and a planing mill,—the saw mill being operated only during the open period of navigation, while the planing mill was operated both winter and summer. The saw mill was destroyed by fire in the fall of 1905 and has not been rebuilt. The planing mill was operated during 1906, but since that date the entire plant has been closed down,—all stop logs being in place at the head works.

No systematic records of water levels appear to have been taken at this point, although during the period from 1898 to 1906 a few valuable readings of a gauge cut in the head works of the plant were

PLATE BB

OLD HEAD RACE OF KEEWATIN LUMBER AND MANUFACTURING COMPANY'S PLANT—SEPTEMBER 11, 1913

HEAD RACE OF LAKE OF THE WOODS MILLING COMPANY'S MILL "A" SEPTEMBER 11, 1913

made by Mr. William Lyon of the Company. A complete description of this gauge appears under "Water Gauges and Bench Marks," page 102. The records appear in Table 12.

Up to the present no record has been obtained with respect to the initial turbine installation or the date of the installation of the turbines which were added from time to time as the plant was enlarged.

A record of the number of turbines operated during the period from 1900 to 1906, together with their sizes and location in the plant, was obtained by the Manitoba Hydrographic Survey from Mr. John A. Miner, a millwright employed by the Company during that period. All the turbines are stated to have been vertical, some of them crudely constructed. No record of the load carried or of the gate operation having been kept, it is evident that any estimate of discharge must be based on other information.

On October 16th, 1905, a discharge measurement was made at this outlet by Mr. H. G. Acres of the Ontario Hydro-Electric Power Commission showing a discharge of 400 cubic feet per second. This discharge presumably represented the water used by both saw mill and planing mill during the open season, or from about the middle of May to the end of October. For the remainder of each year the planing mill alone was operated, and it is estimated that 150 c. f. s. were discharged during the winter. No record has been found stating whether the plant was operated for a 10 hour or a full 24 hour day. Since the saw mill was burned in the fall of 1905, and operation of the planing mill was discontinued in 1906, a certain amount of leakage has taken place through the stop logs at the old head works. The amount of this leakage as determined by discharge measurements of the Manitoba Hydrographic Survey from 1913 to 1915 is given in Table 57.

98896—17——12

HIGH WATER MARKS AND THEIR SIGNIFICANCE

In the absence of extensive records of lake stages, which occurred in a state of nature, physical evidences of prevailing stages become of the utmost importance.

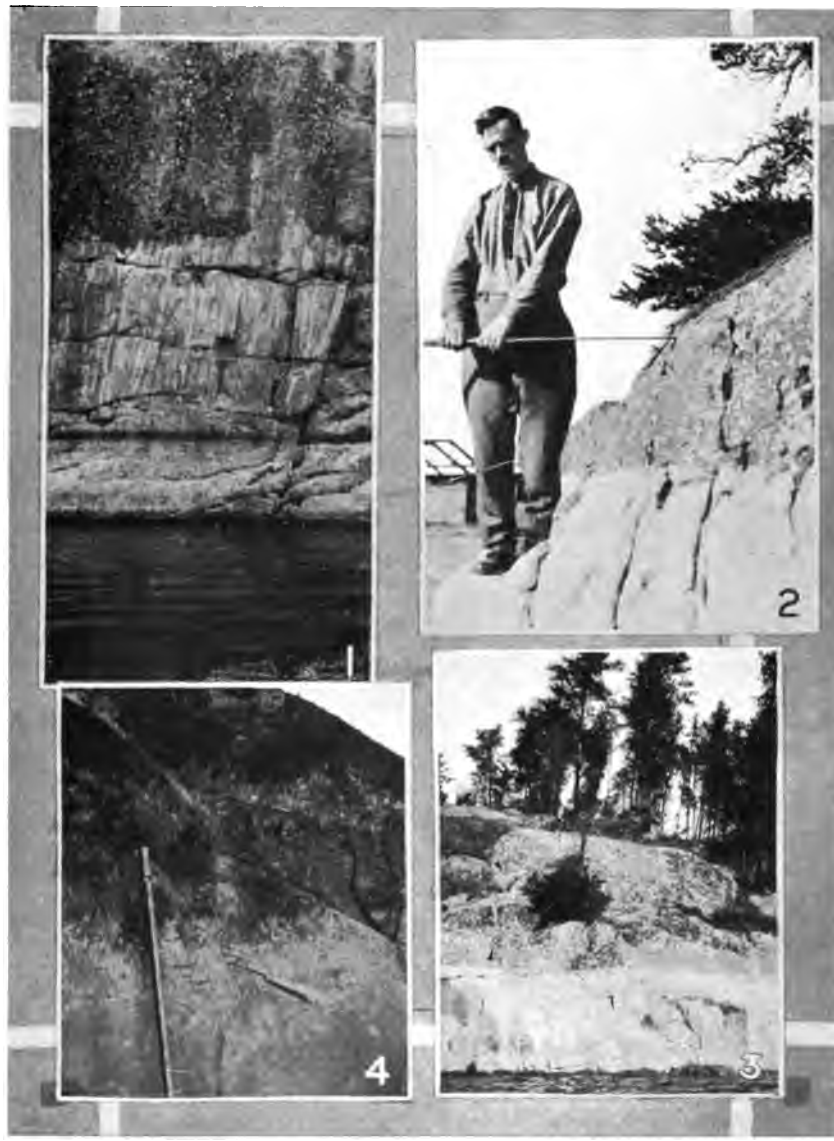
On the watershed of the Lake of the Woods, as elsewhere, these physical evidences consist mainly of various forms of vegetation. The character of the vegetation determines its significance respecting lake stages. Rushes, cat-tail flags, wild rice, and other aquatic grasses grow in water several feet in depth, consequently these plants are of little or no significance in this connection. Some mosses and grasses, and even willows and other small shrubs grow up annually, to a considerable extent, consequently, these forms of vegetation are no index to high lake stages. Tamarack, spruce, balsam, cedar, and black ash furnish no criterion, because these trees are usually found on very wet soil, and frequently in standing water. White, Norway, and jack pine; red, white, or burr oak; basswood or linden, white elm, white ash, birch, poplar, and similar trees of the uplands, on the other hand, do not live where water covers their roots, either very frequently, or continuously for more than a season at a time. Dead trees of these species form a conspicuous fringe around the shores of lakes which, during recent years, have been maintained at a higher level than prevailed in a state of nature.

The bleached appearance of the bark of trees and of the timber on pile bridges and other structures also frequently constitutes evidence of high lake stages. See, for example, Plates BB and FF.

On the shores of the majority of northern lakes, particularly on those situated in the region of archean rock outcrops, water marks, usually referred to as "stains", are almost invariably found on the rocks. Upon closer examination, however, these so-called "stains" are found to consist of the absence of one or more species of lichens for varying distances above the water surface. These lichens, as is well known, are a common form of vegetable growth found on trees and rocks, particularly in northern latitudes. They derive their sustenance from the air, and secrete an acid which disintegrates the rock surface, thereby providing the plants a better foothold. After rains, lichens of one species in particular, common on most northern lakes (*genus gyrophora*) * that are ordinarily crisp and almost black, become leathery and olive green. Submergence in water for a certain time appears to loosen the lichens from the supporting rocks. Some

* A comprehensive work on lichens is Professor Bruce Fink's *Contribution from the United States National Herbarium—The Lichens of Minnesota*, published by the Smithsonian Institution, Washington, D. C., 1910. 269+ xvii pp.; illustrations.

PLATE CC



1. SWIFT WATER AT OLD FORT ISLAND LEFT ONLY UPPER HIGH WATER MARK
2. HIGH WATER MARKS, WINNIPEG RIVER BELOW KEEWATIN BRIDGE
   PADDLE HELD AT UPPER LICHEN MARK (EDGE OF COARSE DARK LICHEN—GENUS GYROPHORA)
   ELEVATION 1017.80 SEA-LEVEL DATUM
   LOWER LICHEN MARK (EDGE OF GREENISH LICHEN—GENUS PARMELIA)
   ELEVATION 1046.36 SEA-LEVEL DATUM
3. DISTANT VIEW OF UPPER AND LOWER LICHEN MARKS BELOW KEEWATIN RIVER BRIDGE
4. UPPER AND LOWER LICHEN MARKS ON WINNIPEG RIVER ABOVE THE DALLES

PLATE DD

HIGH WATER MARKS IN ROCKY NARROWS—RAINY LAKE—OCTOBER 15, 1913

DETAIL OF HIGH WATER MARKS IN ROCKY NARROWS—JUNE 17, 1915

ELEVATION OF LOWER WHITE STRIPE 496.9 PUBLIC WORKS DATUM
ELEVATION OF UPPER WHITE STRIPE 497.4 PUBLIC WORKS DATUM
ELEVATION OF LOWER EDGE OF COARSE DARK LICHEN ON RIGHT SIDE
497.8 PUBLIC WORKS DATUM
ELEVATION OF LOWER EDGE OF COARSE DARK LICHEN ON LEFT SIDE
500.0 PUBLIC WORKS DATUM

PLATE EE

HIGH WATER MARKS ON EASTERLY SIDE OF FERRIS ISLAND—RAINY LAKE
JUNE 17, 1915

PRINCIPAL LOWER LICHEN MARK—ELEVATION 497.8
MARK IN CHANNEL BETWEEN ROCKS—ELEVATION 498.5

HIGH WATER MARKS ON EASTERLY SIDE OF FERRIS ISLAND—RAINY LAKE
JUNE 17, 1915

LOWEST MARK AT EDGE OF SMALL LIGHT GREEN LICHEN—ELEVATION 497.8 PUBLIC WORKS DATUM
NEXT MARK—TOP OF FIRST BAND—SAME LICHEN PARTLY REMOVED—ELEVATION 498.4 PUBLIC WORKS DATUM
SINGLE MARK ON ROCK AT LEFT OF CENTER AND PRINCIPAL MARK ON OTHER ROCKS—EDGE OF COARSE BLACKISH LICHEN—ELEVATION 499.5 PUBLIC WORKS DATUM
EDGE OF COARSE BLACKISH LICHEN ON EXTREME RIGHT—ELEVATION 500.0

species are more persistent than others. Water in motion also appears to remove the lichens more rapidly than standing water, and to remove certain species sooner than others. The character of the rock surface also appears to exert some influence.

On the whole, the small, close growing varieties, particularly the small black lichens (*genus lecanora*), and to a somewhat lesser degree the light green or gray lichens (*genus parmelia*) are more tenacious than the larger, coarser ones (*genus gyrophora*). The larger and much more exposed surfaces of the coarser lichens may be the most important factor governing the earlier removal of these, particularly in flowing water or where subjected to wave action.

Splendid illustrations of the irregular removal of lichen growths, under varying conditions of exposure, are given on Plates DD and EE. The dark coarse lichens of the genus gyrophora were completely removed to elevation 500.0, Public Works datum, on the exposed side of Rocky Narrows in Rainy Lake, but were only slightly removed above elevation 497.8, just around the corner on the sheltered side of the same rock. Similarly, on Ferris Island, also in Rainy Lake, the coarse lichens,—and, where exposed, also the small light green lichens—were removed to elevations varying between 499.5 and 500.0, even though on the sheltered side of the same rocks the small green lichens were only partly removed above elevation 497.8, and were left intact above elevation 498.4.

In the channel between the rocks (upper picture of Plate EE) the lichen mark is at elevation 499.5, whereas on the projecting lip broken loose from the adjoining rock,—no one can say how long ago—the coarse lichens are still growing down to elevation 497.8.

Picture No. 1, on Plate CC, shows the well defined lichen mark in the Winnipeg River at Old Fort Island, elevation 1047.4. Swift water in the contracted channel at this point evidently removed all of the lichens up to the highest elevation which the Winnipeg River gives evidence of ever having reached at this point. This water mark corresponds to the upper high water mark, elevation 1047.8, at Keewatin.

Pictures Nos. 2 and 3, Plate CC, show that in the relatively quiet water of the wide and deep channel, about 350 feet below the Keewatin Bridge, two distinct water marks are visible. The upper one, being the edge of the coarse dark lichens (*genus gyrophora*), is at elevation 1047.8, and the lower one, being the lower edge of the grayish green lichens (*genus parmelia*), is at elevation 1046.35.

Picture No. 4 on the same plate shows, although not so distinctly, two corresponding lichen marks on the banks of the Winnipeg River, a short distance above The Dalles.

The relation between the lichen marks and other forms of vegetation is shown on Plates FF and HH. On Plate FF is reproduced a typical shore scene, photographed on Crooked Lake, September

7th, 1914. Grasses, moss, and small shrubbery, were found growing almost to the water's edge. Next came brush and small trees, then the larger upland trees, and highest of all the lichen growth on the rocks. The lower picture on the same plate, taken on Knife Lake, shows a sharp, well defined, recently formed, water mark, just back of a dead pine which, it will be observed, has a bleach mark on it at the same elevation as the lichen mark on the rocks.

Plate GG shows dead pines on an island in Birch Lake, Minnesota. The picture was taken on July 4th, 1914, when the lake was within one inch of the highest water observed at the dam at the outlet, and within three inches of the lichen mark shown on the rocks in a sheltered place at the upper end of the Lake. Picture No. 2 on this plate shows how water running down the bluff shores of Lac La Croix has removed the lichen from the rocks in streaks.

On several of the boundary lakes, a water mark such as that shown in Picture No. 3, Plate GG, was observed. This mark consists of a deposit, presumably of pollen, from blossoming trees.

It may be remarked that various popular notions respecting the formation of the water marks above discussed, such as abrasion by ice, etc., have been considered and dismissed as untenable, at least in so far as the formation of high water marks on Lake Namakan, Rainy Lake, Lake of the Woods, and on the Winnipeg River below the outlets of the Lake is concerned.

Although we have no exact record of the length of time required for standing water to remove the lichen growth sufficiently to create a water mark, we do know, by observation, that such a mark is formed in a relatively short time, i. e., say, in a single season. This fact is exemplified by the water marks on Little Vermilion Lake, Plate HH and on Knife Lake, Plate FF. When such a mark is once formed, however, a number of years appear to be required to substantially change it. The growth of lichens is exceedingly slow. Several years of low water seem to be required for the lichens to grow downward sufficiently to remove even the sharpness of a water mark and to produce a ragged edge.

In connection with the slow growth of lichens, Dr. Frederick V. Coville, Curator of the United States National Herbarium, in a communication to Mr. White, dated February 20th, 1914, states:

> "You may be interested to know that on a lichen-covered rock on Plummer's Island in the Potomac near Washington some giant caps were set off in the summer of 1906. The caps on exploding blew away the lichens and the rock surface over a diameter of six inches to a foot. It was several years before any of these spots showed even a trace of new lichen growth and even now the spots are clearly discernible because their lichen covering is fragmentary and imperfect. This is presumably due to lack of adequate disintegration of the fresh rock surface exposed by the explosion of the caps as well as to the slow growth of the lichens themselves."

A HOMESTEAD ON RAT ROOT RIVER—NOTE FARM YARD FENCE IN WATER—1914

WATER-KILLED OAKS—RAT ROOT RIVER—1914

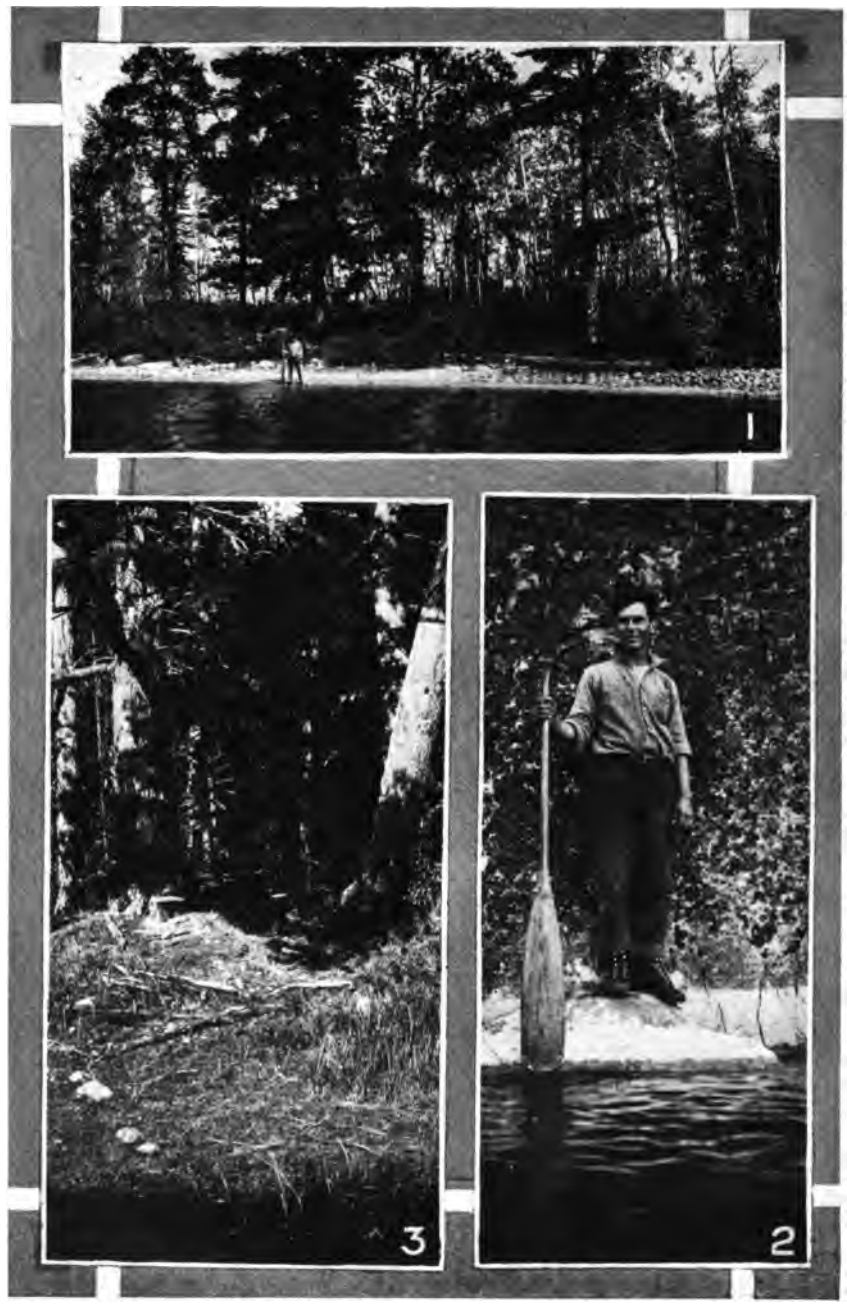
TYPICAL SHORE SCENE SHOWING RELATION BETWEEN HIGH WATER MARKS AND GROWING TREES AND BRUSH—CROOKED LAKE—SEPTEMBER 7, 1914.

BLEACH MARKS ON RECENTLY KILLED TREES AND LICHEN MARKS NEWLY FORMED ON ROCKS—KNIFE LAKE—SEPTEMBER 5, 1914

PLATE GG

1. Dead Pines on Island in Birch Lake, Minn.—July 4, 1914
2. Lichen on Bluff Shore of Lac La Croix, Removed in Streaks, by Running Water
3. "Chalk" Water Mark on Lac La Croix 3 Ft. Above Water—Sept. 8, 1914
   This mark consists of a deposit, presumably pollen from trees
4. Birch Lake, Minn., Within 1 Inch of Highest Observed Water and Within 3 Inches of Lichen Mark—July 4, 1914

PLATE HH



1. LARGE PINES GROWING FAR BELOW EXTREME HIGH WATER MARK, LAC LA CROIX—SEPTEMBER 8, 1914
2. HIGH WATER MARK ON LITTLE VERMILION LAKE—SEPTEMBER 9, 1914
3. PAPER ON NORWAY PINE AT ELEVATION OF WATER MARK 5'-0" ABOVE WATER SURFACE, LAC LA CROIX—SEPTEMBER 8, 1914

EXTREME HIGH WATER MARK ON LAC LA CROIX WAS 8'-5" ABOVE WATER SURFACE ON SEPTEMBER 9, 1914

Inasmuch as these high water marks on the rocks, consisting of the entire or partial absence of certain species of lichens, are quickly formed and very slowly changed, it must be apparent that these marks represent only the *highest lake stages* reached, for more than a few days at a time, in the course of perhaps twenty-five years or more; and further, that in exposed positions these water marks reflect wave action, and hence represent elevations somewhat higher than the highest stage of quiet water. Such water marks, resulting from very high stages, then, cannot rationally be regarded as an index to *ordinary high water*. On the navigable waters of Minnesota, the Federal Government holds an easement, in the public interest, in the land lying between low water and ordinary high water, consequently the meaning of the term "ordinary high water" is important.

In 1908, when having the subject of possible damage to riparian owners on the Lake of the Woods under its consideration, the Office of the Chief of Engineers, United States War Department, in a memorandum dated February 25th, 1908, and transmitted by the Secretary of War to the Secretary of State, states:

"As the Lake of the Woods is a navigable water of the United States, and Congress has exercised jurisdiction by making an appropriation for the improvement of Warroad Harbor with the view of a lake level of 7.2 feet, it is thought that the question of possible damage to riparian owners by the maintenance of that level must be considered upon the basis of the relation to ordinary high water mark under natural conditions, and not to the normal lake level."

In the Minnetonka decision * Judge Mitchell defined ordinary high water as follows:

" * * * * * But, in the case of fresh-water rivers and lakes,—in which there is no ebb and flow of the tide, but which are subject to irregular and occasional changes of height, without fixed quantity or time, except that they are periodical, recurring with the wet or dry seasons of the year,—high-water mark, as a line between a riparian owner and the public, is to be determined by examining the bed and banks, and ascertaining where the presence and action of the water are so common and usual, and so long-continued in all ordinary years, as to mark upon the soil of the bed a character distinct from that of the banks, in respect to vegetation, as well as respects the nature of the soil itself.

" 'High-water mark' means what its language imports,—a water mark. It is coordinate with the limit of the bed of the water; and that, only, is to be considered the bed which the water occupies sufficiently long and continuously to wrest it from vegetation, and destroy its value for agricultural purposes. Ordinarily, the slope of the bank and the character of its soil are such that the water impresses a distinct character on the soil, as well as on the vegetation. In some places, however, where the banks are low and flat, the water does not impress upon the soil any well-defined line of demarcation between the bed and the banks. In such cases, the effect of the water upon vegetation must be the principal test in determining the location of high-water mark, as a line between the riparian owner and the public. It is the point up to which the presence and action of the water is so continuous as to destroy the value of the land for agricultural purposes by preventing the growth of vegetation, constituting what may be termed any ordinary agricultural crop,—for example, hay.

* In re Minnetonka, 56th Minnesota. See "Final Arguments," Washington, April, 1916, pages 242-244.

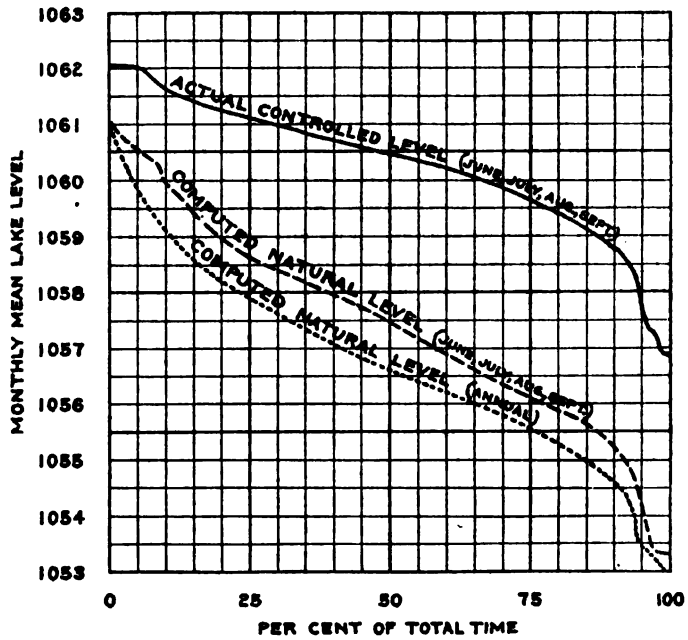
This line of demarcation between land and water growths is usually quite distinct on the northern lakes, as shown on Plates FF and HH, for example. The vegetation growing at the lowest elevation consists of a straggling growth of grasses and some mosses which may reach down to the water's edge even in low water. Above these growths there is a well defined margin of brush and small trees, and still a little higher up are found the larger upland trees.

On all of the lakes examined on the Lake of the Woods watershed, whose outlets were still in natural condition, large pines, oak, elm, and basswood trees were found growing far below the highest water marks formed by the lichens on the rocks. This fact is well illustrated by the photographs of portions of the shore line of Lac La Croix, shown on Plate HH. There are two pronounced lichen marks on this lake; the upper one on September 8th, 1914, was 8′ 5″ above the water surface, and the lower one, which is the more sharply defined one of the two, was 5′ 0″ above the water on the same date. The pictures on Plate HH clearly show large trees growing at elevations ascertained to be less than 5 feet above the water surface. If lake stages of the elevation of the upper lichen mark had prevailed for a large portion of the time, these large trees certainly would never have grown up. If the lake were raised 8′ 5″ above the elevation found on September 8th, 1914, and kept at that elevation, most of these trees would die in a single season.

Since, then, the lichen marks on the rocks are an index, only, to extreme high stages, these marks do not fix a line of demarcation between the rights of riparian owners and the right of the Federal Government of the United States, for example, to the use of the shores of the Lake of the Woods, between low water and ordinary high water, for the public use of navigation. Considering the Lake as a whole, moderately high stages unquestionably aid navigation. The right of the riparian owner to the full enjoyment of his property down to ordinary high-water mark, however, cannot be impaired without compensation. Inasmuch as the level of the Lake of the Woods has, during the past twenty-eight years, been maintained at an elevation averaging practically three feet above that which would have prevailed under natural conditions, the character of the bed of the Lake and of the banks, and the character of the vegetation now found on the shores of the Lake, do not offer a satisfactory index to ordinary high water as it existed in a state of nature. Recourse, then, must be had to some other method of determining the elevation of ordinary high water on the Lake of the Woods in a state of nature. In discussing the subject of prevailing levels on the Lake, we will point out that a level of 1059 would, under natural conditions, have been exceeded for periods aggregating nearly two and one-half years out of the past twenty-three, or a little less than 11 per cent of the time.

Ordinary high water, from the viewpoint of the riparian owner, however, depends upon the stages which prevail during the planting, growing, and harvesting seasons rather than on those which prevail throughout the year considered as a whole.

The following figure shows the levels which would have prevailed on the Lake of the Woods, if the outflow had not been controlled, during the months of June, July, August and September for the period of years extending from January 1st, 1893, to December 31st, 1915.



FREQUENCY CURVES
SHOWING COMPUTED NATURAL LEVELS
LAKE OF THE WOODS
FOR THE
MONTHS OF JUNE JULY AUGUST SEPTEMBER
1893-1915

It appears from this curve that a level of 1059, or above, would, under natural conditions, have prevailed about 20 per cent of the time. This stage would have been reached or exceeded during six out of the twenty-three agricultural seasons during this period of years. Considering all stages above the average prevailing during the agricultural season as high stages, and those below the average as low stages, the level of 1059 represents a high stage which would have been exceeded under natural conditions, during nearly half of all the agricultural seasons during which the level of the Lake would have risen above the average.

KENNEDY HIGH WATER MARKS ON LAKE OF THE WOODS

Even though the growth of lichens, constituting water marks, is exceedingly slow, yet in the course of twenty-five years some changes in these marks are certain to occur. These changes, however, are likely to be so gradual as to escape casual observation. The water marks on the Lake of the Woods, for example, were known to the earliest settlers. It is not generally known, however, that the elevation of these marks actually has changed somewhat during past years.

In this matter we are exceptionally fortunate, however, in having a permanent and indisputable record of what was the elevation of the highest lichen mark on the Lake of the Woods twenty odd years ago.

In September, 1895, Mr. James C. Kennedy, Resident Engineer for the Keewatin Power Company, at the request of Mr. John Mather, visited certain places on the shore of the Lake of the Woods, and had a line with the letters **HW** above it (**HW**) cut into the rocks on line with the highest lichen mark shown on these rocks.* In this connection, Mr. Kennedy filed an affidavit on September 13th, 1895, as follows:

"DOMINION OF CANADA,
District of Rainy River.

To Wit

I, James Crow Kennedy Civil Engineer at present acting as resident Engineer on the construction of the works of "The Keewatin Power Company (Limited)"

Do solemnly Declare that I was instructed by Mr. John Mather, vice President of the aforesaid Company to mark at several places on the shores of the Lake of the Woods, and cut into the rocks forming the same the mark **HW** on a water-line as shown on the said rocks.

In carrying out these instructions I did on the tenth day of September 1895 and following days proceed to certain parts of the Lake of the Woods indicated on the accompanying map by circles drawn in black lines coloured blue inside with my signature made at each circle the description of the localities on the map where these circles and my signatures are made being as follows viz.—

One at the westerly shore of the East Branch of the Winnipeg River at outlet from Lake of the Woods and at a point about 100 yards eastward of the main line of the Canadian Pacific Railway.

One at northeasterly shore of Island designated "D. 91" Deacon's Survey and lying next the westerly mainland shore of Rat Portage Bay.

One near the most easterly point of the shore of Bucketé Island (31G) lying at mouth of the North West Angle Inlet—and

One in American Territory at the Northeasterly shore of Flag Island Point and near easterly entrance to strait between Flag Island Point and Passage Island.

The said map is called a "Geological and Topographical Map of the northern part of the Lake of the Woods and adjacent Country, by A. C. Lawson M. A. 1885 and issued by the Geological and Natural History Survey of Canada, Alfred E. Selwyn C.M.G. L.L.D. F.R.S. &c Director" 1887.

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*See Appendix IV, p. 267.

I hereby certify that I did cut on rocks forming the shores of the Lake of the Woods at the aforesaid places marked on the map and signed by me the marks HW for the purpose of showing what indicates a water mark on the Lake at a time for which I can fix no date. It is very distinctly seen on the shores nearly everywhere and leaves no doubt that it is a watermark showing the height at which the water in the Lake stood—I find that to be the belief of the people in the district and also of those who do business on The Lake of the Woods. Furthermore, that is corroborated by another mark about eighteen inches lower that was made by the water in 1888 when it stood for some time at that level at present well known to be a fact.

And I make this solemn Declaration believing the same to be true and by virtue of the Act respecting extra judicial oaths

(sgd) JAS. C. KENNEDY

Declared before me at the village of Keewatin in the District of Rainy River this 13th day of Septembr A. D. 1895

(sgd) R. A. MATHER
A Notary Public for Ontario."

Under date of March 10th, 1913, Mr. Kennedy wrote as follows, respecting the establishment of these water marks:

"I have a distinct recollection of adopting certain Bench Marks previously established by Mr. Turnbull, C. E. in making surveys for the Keewatin Power Co. and of adhering to his datum level throughout my service with the same Company as Resident Engineer in charge of the construction of the "Keewatin Dam". Normal high water of the Lake was 100′ above datum.

I have a further distinct recollection of tieing in with my adopted datum the elevation of the HW mark cut in the rock in Rat Portage Bay near the C. P. Railway, in order to make a relative record, and which record will show the HW mark at the location just described, to be 102.54 feet above that datum."

With further reference to the establishment of these high water marks and their elevation in terms of Kennedy's "100" datum, the following record from one of Mr. Kennedy's note books under date of November 18th, 1898, is of interest:—

"Water level of Lake at 8 A. M.... 100.00 } calm
Water level of Lake at 3 P. M..... 100.00 }

Measured distance of HW mark down to water level of bay 2.37 ft., thus establishing the HW mark clearly defined by lichen edge on the rocks forming shores of bay immediately south of Railway Fill as 102.37 or same level practically as HW cut mark of K. P. Co. near floating bridge, which is 102.54.

102.40 is one level of HW mark by moss &c. found in April, 1895—and recorded."

On Plates II and JJ are shown photographs of the various Kennedy high water marks.

The mark on Tunnel Island, as is clearly shown in the photograph, Plate II, is located about .2 foot above the present water mark, as defined by the lichen growth. The elevation of this mark, as determined by instrumental levels by the Engineers of the Manitoba Hydrographic Survey, is 1062.58 sea-level datum.

According to Mr. James C. Kennedy's affidavit, a water mark was cut on Island "D 91". This, however, appears to be an error in

identification of the island, as no such mark has been found on the island "D 91", but on island "S 565" instead. The location of the latter island agrees with Mr. Kennedy's description as lying at the westerly main shore end of Rat Portage Bay. This mark is also covered by lichen growth. Its elevation above sea-level datum, as determined by Mr. Scovil of the Manitoba Hydrographic Survey, who found the mark, on June 17th, 1913, 10.30 a. m., (lake calm) by water level transfer from Keewatin, is 1062.36 sea-level datum.

Kennedy's high water mark on Bucketé Island was also found by Mr. Scovil, and its elevation, 1062.91, determined by water level transfer from Oak Island on June 25th, 1913. The elevation of this mark, as determined by Mr. White on July 9th, 1914, also by water level transfer from Oak Island, is 1062.96. This high water mark is also somewhat overgrown with lichen, although approximately on line with a well defined, existent, lichen mark.

The elevation of the high water mark on Flag Island Point, as determined by us at 12 m. on June 14th, 1913, by water level transfer from Oak Island, (lake calm) is 1062.73. The elevation as determined by Mr. Scovil, by water level transfer from Oak Island (strong south wind, lake rough), at 12.30 p. m., June 24th, 1913, is 1063.01. Although there are some small close-growing black lichens (*genus leconora*) scattered on the rock below Kennedy's mark, the present high water mark as defined by the coarse dark lichens, is several tenths of a foot higher.

Evidently there have been small, though nevertheless perceptible, changes in the elevation of these lichen marks. It may be presumed that if Kennedy had established his high water marks at the time the pictures of Plates II and JJ were taken, he would have placed the Tunnel Island mark about .2 foot lower, and the Flag Island Point mark several tenths of a foot higher. The changes in high water marks indicated by the photographs have apparently resulted from wave action extending over relatively long periods of high water such as have prevailed at times during the past twenty years. Although standing water during these past twenty years, when the lake was calm, did not reach an elevation greater than 1062.35, yet wave action has unquestionably resulted in removing the coarser lichens from the rock surface in exposed locations such as that at Flag Island Point, to a considerably higher elevation. In sheltered locations, however, such as at Tunnel Island, the slightly lower stage has permitted the lichens to grow downward about .2 foot.

Stages of 1062 and above have, without doubt, prevailed for longer periods at a time, during the past twenty years than they did in a state of nature, consequently there has been a better opportunity, in exposed locations, for wave action to remove the lichens to a higher elevation than they occupied during the period of years

LEFT—KENNEDY'S HIGH WATER MARK ON TUNNEL ISLAND IN RAT PORTAGE BAY ELEVATION 1062.58 SEA-LEVEL DATUM—PHOTO SEPTEMBER 21, 1912

RIGHT—KENNEDY'S HIGH WATER MARK ON ISLAND S565 IN RAT PORTAGE BAY ELEVATION 1062.36 SEA-LEVEL DATUM—PHOTO JUNE 17, 1913

KENNEDY'S HIGH WATER MARK ON BUCKETE ISLAND AT ENTRANCE TO NORTHWEST ANGLE INLET—ELEVATION 1062,96 SEA-LEVEL DATUM—PHOTO JULY 9, 1914

PLATE JJ

GENERAL VIEW SHOWING LOCATION OF KENNEDY'S HIGH WATER MARK ON FLAG ISLAND POINT

DETAIL OF KENNEDY'S HIGH WATER MARK ON FLAG ISLAND POINT—NORTHWEST ANGLE INLET—ELEVATION 1062.73 SEA-LEVEL DATUM—JUNE 14, 1913

previous to the date on which Kennedy established his marks. This effect of wave action apparently is exemplified, even though in a lesser degree, by the difference in elevation between the Kennedy high water mark in the sheltered location near Kenora and that in the exposed location on Flag Island Point.

Further evidence of the gradual extension of lichen growths is furnished by the photographs of the Kennedy high water marks of Plate II. Apparently a panel was cut in the rock surface before the letters HW were inscribed. This panel, particularly in case of the Tunnel Island mark, was, in 1912, completely covered with small sized specimens of the light green lichens of the *genus parmelia*, although lichens of the *genus gyrophora* apparently were still absent.

RATING CURVE OF OUTFLOW FROM LAKE OF THE WOODS IN STATE OF NATURE

Early in 1895, during the construction of the Norman Dam, Mr. James C. Kennedy established a number of gauges on the Western Outlet of the Lake of the Woods, between the Lake and the site of the dam.

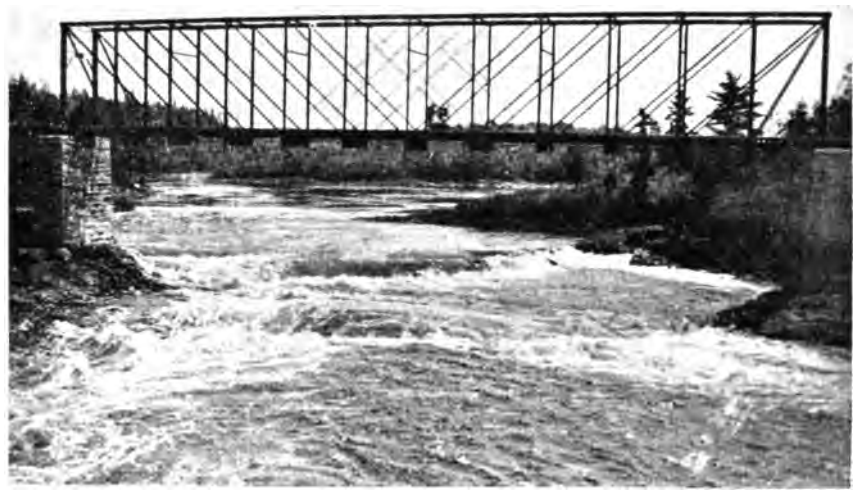
These gauges were located just above the crests of the various rapids, and their readings reflected changes in the water level at the Norman Dam resulting from the construction of the rock fill portion of the dam and from the subsequent placing of the stop logs in the sluices of the completed dam. The locations of these slope gauges are shown on the map of the Western Outlet, Plate 25, and the gauge readings are assembled in Table 25.

The principal point of natural control of outflow from the Lake of the Woods, through the Western Outlet, is the contracted reach of the channel at the Canadian Pacific Railway bridge, particularly Sections 16, 17, and 18, Plate 30. Most of Kennedy's slope gauge readings were taken while the principal portion of the old Rollerway Dam (built at the outlet of the Lake in 1887), was still in place, but they were taken before the operation of the Norman Dam affected the discharge through the control sections at the C. P. R. bridge.

With the aid of the readings of these Kennedy slope gauges and other available data, it is possible to deduce a rating curve of outflow from the Lake of the Woods in a state of nature, and thus to compute the levels which would have prevailed on the Lake during recent years, if the controlling structures on the various outlets had not been present.

On Plate 107 are presented curves showing, first, the relation between lake levels and tail water levels at Keewatin during 1892–1895; second, the relation between water levels at Kennedy's Gauge No. 7 and tail water levels during 1895; and third, the relation between water levels at Gauge No. 7 and the fall from the Lake to this gauge during the same year. These curves are based on the readings of the Kennedy lake, tail water and slope gauges, assembled in Table 27. In plotting these data, the observed tail water levels at Norman have been reduced to their equivalent readings at Keewatin by the subtraction of from .1 to .2 of a foot, in accordance with the relationship previously demonstrated as existing between Norman and Keewatin tail water levels.

PRESENT CANADIAN PACIFIC RAILWAY BRIDGES—WESTERN OUTLET—1913



Courtesy of Mr. T. C. Mills and Manitoba Hydrographic Survey

RAPIDS AT CANADIAN PACIFIC RAILWAY BRIDGE PRIOR TO COMPLETION OF NORMAN DAM

LOOKING TOWARD NORMAN TRAFFIC BRIDGE FROM CANADIAN PACIFIC RAILWAY EMBANKMENT

NOTE EDDIES AND CURRENTS APPROACHING CONTROL SECTION AT C. P. R. BRIDGE

It will be noted that for water levels of about 1056.75, at Gauge No. 7, the observed values of fall from the Lake to Gauge No. 7 vary considerably. The points falling to the left of the curve show a reduction in fall which represents backwater, resulting from the first placing of stop logs in the Norman Dam on August 21st, 1895. The points falling above the rating curve of Gauge No. 7 indicate a rise in the water level at this point without a corresponding change in tail water level. Inasmuch as a uniform tail water level represents uniform discharge and, in the absence of stop log manipulation, a constant lake level, the rise at Gauge No. 7 inevitably reduced the fall between the Lake and this gauge. This reduction in fall without change in discharge also indicated that the outflow from the Lake was still being controlled by the Rollerway Dam.

The fact that the curve of "Fall", Plate 107, shows rapidly decreasing fall with increasing lake stage, indicates that as the lake stage increased, control gradually passed from the Rollerway Dam to the contracted section at the C. P. R. bridge, and that at extremely high lake stages the Rollerway would no longer restrict the outflow from the Lake.

On Plate 108 are shown rating curves of discharge through the various outlets of the Lake of the Woods during the year 1895, plotted against the observed readings of Kennedy's Gauge No. 7. While the discharge through the mills and power plants, for that year, is not known very accurately, yet the adopted value of 900 c. f. s. for the summer months—consisting of a flow of 350 c. f. s. through Mill "A", 400 c. f. s. through the Keewatin Lumber & Manufacturing Company's plant, and 150 c. f. s. through the Kenora plant—and the adopted value of 700 c. f. s. during the winter months—consisting of 350 c. f. s. through Mill "A", 150 c. f. s. through the Keewatin Lumber and Manufacturing Company's plant, and 200 c. f. s. through the Kenora plant—are believed to be substantially correct. The discharge through the Eastern Outlet referred to gauge No. 7, shown on this Plate 108, is deduced from the rating curve, Plate 68, previously discussed, and the curves of "Fall" on Plate 107. The curve of discharge designated "All outlets" has been deduced from the curve designated "At Gauge No. 7 (1895)" on Plate 107, showing the relation between water level at gauge No. 7 and tail water level, and the rating curve of discharge, Plate 70, showing the relation between tail water level and discharge. The curve of discharge through the Western Outlet, then, represents the difference between the discharge through all outlets, and that through the Eastern Outlet combined with the discharge through the mills and power plants. It will be noted that the discharge measurement made by Kennedy on May 26th, 1893, falls almost exactly on this curve of Plate 108, and substantiates what we believe to be a correct deduction.

Having now deduced a rating of the discharge through the Western Outlet in terms of water levels at Kennedy's Gauge No. 7, it becomes necessary, in order to secure a rating of the discharge through the Western Outlet in terms of lake levels, to determine what the probable fall was in a state of nature (with the Rollerway Dam out), between the Lake and Kennedy's Gauge No. 7, located just above the rapids at the C. P. R. bridge. The mode of determination of this relationship will next be explained.

From 1912 to 1915 inclusive, measurements were made, by the Manitoba Hydrographic Survey, of the discharge through the Western Outlet. At the same time readings were taken of slope gauges located at various points along the channel between the Norman Dam and the Lake. One of these gauges (No. 3) was placed as closely as possible to the location of Kennedy's Gauge No. 7, as determined from the map and notes accompanying the Kennedy records.

By means of the well known Chezy formula, $v = C\sqrt{rs}$, and the discharge data and areas of cross sections of the channel determined by the Manitoba Hydrographic Survey, the average value of the coefficient "C", was found to be 26.0 for the Western Outlet between the Lake and the C. P. R. bridge and to be practically uniform for rates of discharge of 8,000, 13,000, and 18,000 c. f. s. at stages varying between 1060 and 1061.

Using a value of 26.0 for the coefficient "C", the fall between the Lake and Kennedy's Gauge No. 7 was computed for various rates of discharge. Adding this computed fall to the water level at Gauge No. 7, the lake level in a state of nature, corresponding to the given rate of discharge through the Western Outlet, shown on Plate 109, is obtained.

While the value of 26.0, adopted for the coefficient "C", may appear low, it is believed to be substantially correct, because, in the first place, it is based upon observed values under present conditions, reasonably similar to those which existed in the Western Outlet before the construction of the Rollerway Dam; and in the second place, it is in agreement with other recent determinations as well as with the views of hydraulic engineers expressed in technical literature.

On Page 359 of "A Treatise on Hydraulics" by Hughes and Safford, published in 1913, observed values are given for the coefficient "C", ranging mostly between 40 and 50 for deeper and much more nearly regular and uniform cross sections of channel than those under consideration.

On Page 827 of "Engineering News" for April 29th, 1915, Mr. R. E. Horton comments on the fact that coefficients of roughness for natural river channels are much larger than commonly supposed. Larger coefficients of roughness indicate smaller values for the Chezy

coefficient "C". The values of coefficient of roughness of .06 to .10, mentioned by Mr. Horton, as of common occurrence at low stages on streams, would give values of "C" even below those here used.

In connection with his work on the Mississippi River between Minneapolis and St. Paul, Mr. Meyer observed values of the coefficient "C" as low as 29 for moderately rough, gravel river bed, with some boulders and a mean depth of about 5.0 feet.

If higher values had been used for the coefficient "C", in computing the fall between the Lake and Kennedy's Gauge No. 7, the result would have been somewhat lower lake stages for the same rates of discharge.

Having, now, deduced rating curves of discharge through both the Eastern and the Western Outlets in a state of nature, before the construction of any controlling works at the outlets of the Lake, these two curves are readily combined into a rating curve of discharge through all outlets of the Lake *in a state of nature*, for lake stages up to about 1059.0, as given on Plate 110. In order to secure a rating of the discharge for higher lake levels, it was necessary to extend the curve. This has been done upon the basis of what we have every reason to believe is a legitimate assumption, namely, that the Kennedy high water mark cut into the rock shore of the Lake, in 1895, in the sheltered location on Tunnel Island on the Eastern Outlet (see discussion of Kennedy High Water Marks), records a Lake level which practically corresponds to a tail water level defined by the upper high water marks, clearly visible on the rock shores in the tail water bay at Keewatin, and also at many other places on the Winnipeg River below the outlets of the Lake. (See profile of water levels, Plate 22.) The discharge corresponding to the average elevation of these high water marks in the bay at Keewatin is taken from the tail water rating curve of discharge through all outlets of the Lake, Plate 70, and is plotted against the elevation of the Kennedy high water marks in the Lake. This point is then joined to the computed lower portion of the rating curve of discharge, giving the final curve of outflow from the Lake of the Woods in a state of nature, i. e., through all natural outlets, unaltered and unrestricted by dams or other controlling works.

In order to further substantiate the credibility of the deduction just made with respect to the outflow from the Lake of the Woods in a state of nature, there are presented the curves of Plate 111, showing the effect of the Rollerway and the Norman Dam on the relationship existing between lake levels and tail water levels. The curve of "Rollerway and Norman Dam Both Out, (State of Nature)", is derived from the rating curves of Plate 110, by merely plotting lake levels against the tail water levels corresponding to a given rate of discharge. The lower end of the curve of "Rollerway in and

Norman Dam Open" is based on the Kennedy lake and tail water records, and is well defined for lake stages up to 1061. The upper end of the curve is fixed by the high water record of 1897.

The curve of "Rollerway Out and Norman Dam In" is well defined at the upper end by a number of readings assembled in Table 30, taken from the graphs of Mean Lake Levels and of Mean Tail Water Levels at times when the Norman Dam was either wide open or nearly so. Three of the points plotted fall above the curve, because the dam was not quite wide open at the time, three rows of stop logs having been left in. The fact that all of the points on this curve above a lake stage of about 1060.5 fall above the curve of "Rollerway In and Norman Dam Out", indicates that at high stages the Norman Dam, even when wide open, restricts the outflow from the Lake of the Woods, and that such portions of the old Rollerway Dam as still remain, in the shape of boulders and debris on the river bottom, do not restrict the discharge during these higher stages. With the Norman Dam wide open, it is certain that these remains would, in some measure, restrict the discharge from the Western Outlet at the lower stages of the Lake.

PREVAILING LEVELS ON LAKE OF THE WOODS IN A STATE OF NATURE

In discussing the significance of high water marks we stated that the highest water impressions made on the lichens growing on the rocky shores of the Lake of the Woods and the marks cut on these rocks by Mr. J. C. Kennedy, in 1895 constitute *extreme* high water marks, and give no indication of *ordinary* lake stages. Now, before a reply can be formulated to the second question of the Official Reference—and it is not here the intention to construe the Reference—it is necessary to know what may fairly be considered as, "the normal or natural level of the Lake."

Having deduced the "Rating Curves of Outflow from Lake of the Woods in a State of Nature," Plate 110, and having also substantially correct values for the inflow into the Lake during the past twenty-three years, it becomes possible to compute the levels which would have prevailed on the Lake during these years, provided the outlets had been in their natural condition, and thus to obtain a range of natural levels over a considerable period of years with which to compare ranges of controlled levels which have prevailed, or which may be recommended.

In computing natural levels, the choice of the particular level which it is necessary to assume as prevailing at the beginning of the period over which the computations extend is of no practical consequence. In order to demonstrate this fact the curves of Plate 113 were prepared. Four curves are shown on this Plate, one giving the actual observed levels for the twelve months from October, 1892, to September, 1893, and three showing the natural levels for the same period computed on the basis of the following assumptions respecting the level existent at the beginning of the period:

(*a*) That the level which prevailed on October 1st, 1892, was a natural level.

(*b*) That the natural level on October 1st, 1892, was 1059.5, Sea-level datum.

(c) That the natural level on October 1st, 1892, was 1057.0, Sea-level datum.

It is apparent from the curves of Plate 113 that even though a level which is several feet in error be assumed to prevail at the beginning of the period, the computed natural level, by the end of twelve months, would be substantially correct,—in fact most of the error would have been eliminated in half that time. In our submitted computation of natural lake levels it was assumed that, under

natural conditions, a stage of 1059.5 would have prevailed on October 1st, 1892.

After computing natural levels, for Lake of the Woods, by an analytical method used by Mr. Meyer about ten years ago in a similar study involving the computed natural outflow from the upper Mississippi River Reservoirs in connection with floods on the river at Aitkin, Minnesota, our principal office assistant, Mr. Shepard, devised the curves of Plates 112 and 105, which show the relationship between rate of inflow, lake levels and change in stage, for Lake of the Woods and for Rainy Lake. Although the results derived by the two methods do not differ substantially, yet the use of these curves results in greater accuracy and a great saving of time. Both methods are based on the assumption of uniform rates of change in stage during ten day periods. While this assumption involves what at first sight may appear to be an appreciable error yet the actual resulting error in levels is really inappreciable because the several small errors are compensatory.

The use of the curves, Plates 105 and 112, can best be understood by first explaining their construction. In the first place, under natural conditions, that is, without any control at the outlets, each lake stage corresponds to a known rate of *outflow* (Plates 83 and 110), and if the net rate of *inflow* during any ten day period equals the rate of outflow during the same period then the Lake will neither rise nor fall.

The curves on Plates 105 and 112, designated "Constant Lake Stage", represent, for any given lake stage, the mean rate of inflow which must prevail for the succeeding ten days in order that no rise or fall in lake stage shall occur. By way of illustrating the application of the curves of Plate 112, suppose that at the beginning of a ten day period the Lake of the Woods has an elevation of 1060.00, and that a rise of one-tenth foot occurs during the succeeding ten days. Assuming a uniform rate of rise, the mean stage during such ten day period would be 1060.05. Now, the rate of natural outflow corresponding to a lake stage of 1060.05 is 29,860 c. f. s., and a rise of .10 foot on the Lake of the Woods in ten days is equivalent to a rate of flow of 4,792 c. f. s., consequently the rate of inflow required to raise the Lake one-tenth foot in ten days is 29,860 plus 4,792 or 34,652 c.f.s. We have thus obtained one point for a curve to be used for representing a rise of one-tenth foot in the stage of the Lake of the Woods. Proceeding in a similar manner, a sufficient number of points were computed to permit the construction of the several curves of Plate 112, which represent the various changes in stage occurring during ten day periods and extend over a range of levels on Lake of the Woods from 1051.00 to 1063.00.

Because of the fact that, in a state of nature, Shoal Lake, with an area of 107 square miles, or 7.2 per cent of the total area of the Lake of the Woods and Shoal Lake, did not drain to as low a stage as Lake of the Woods, the lake area usable in computing storage on the Lake of the Woods varies. On the basis of the best available information respecting the natural condition of Ash Rapids, at the outlet of Shoal Lake, it was assumed that when the level of the Lake of the Woods fell below a stage of 1055, sea-level datum, water drained from Shoal Lake into the Lake of the Woods; and that above 1057 the two lakes rose and fell together, the change from one condition to the other occurring gradually.*

The use of these curves of Plate 112 in computing natural lake levels may be illustrated as follows: Assume that the level of the Lake of the Woods at the beginning of a ten day period is 1058, and that the inflow during the next ten days averaged 40,000 c. f. s. According to the curves of Plate 112 these conditions would result in a rise in stage of .4 foot in ten days, making the stage at the end of the period 1058.4. Again, assume that during the second ten days the rate of inflow is only 30,000 c. f. s. For this condition the curves give a rise in stage of 0.17 foot, thus making the stage at the beginning of the third ten day period 1058.57.

In these computations the months have been divided into three periods, of which the first two are each ten days in length, consequently the last period in each month consists of either 8, 9, 10 or 11 days. The rise or fall for such periods has simply been taken as .8, .9, 1.0 or 1.1 times the values taken off the curve for a ten day period.

The curves for Rainy Lake, Plate 105, are similar in construction, and identical in application, the only difference being that a uniform lake area of 345 square miles, for Rainy Lake, has been used in the construction of the curves.

It is appreciated, of course, that considerable ground storage capacity exists around the southerly shore of the Lake of the Woods and around portions of Rainy Lake. However, fluctuations in lake stage in a state of nature are sufficiently similar to fluctuations in a state of control to permit disregarding ground storage in these computations.

Owing to the fact that the level and outflow from Rainy Lake have been under control since March, 1909, and from Lake Namakan since March, 1914, it is necessary to compute what the natural outflow from these lakes would have been, subsequent to these dates, in order that the natural inflow into the Lake of the Woods during the years 1909 to 1915 may be obtained, and the natural level computed.

The natural inflow, and consequently also the natural level and outflow from Lake Namakan for 1914 and 1915, are obtained from

*Under certain conditions the direction of flow is reversed.

the relation existing in 1912 and 1913 between natural inflow into Namakan and the natural inflow into Rainy Lake from the remainder of the watershed. Previous to 1914 the inflow into Rainy Lake was practically uncontrolled, consequently, using the computations for Namakan in 1914 and 1915, it is possible to compute the natural inflow into Rainy Lake up to the end of 1915. The computed natural level of Rainy Lake is obtained by the use of the natural inflow and the curves of Plate 105, as explained previously for the Lake of the Woods. The natural outflow is then obtained from the average level and the rating table, Table 98.

The computed natural *outflow* from Rainy Lake is then combined with the runoff from the remainder of the watershed tributary to Lake of the Woods, as ascertained by subtracting the observed outflow from Rainy Lake from the observed inflow into the Lake of the Woods. The natural inflow into the Lake of the Woods between March, 1909, and December 31st, 1915, is thus obtained and the natural level of Lake of the Woods for this period can then be computed in the manner previously explained.

The computed natural levels, together with the actual observed levels on Lake of the Woods, from 1893 to 1915, are shown on Plates 114 to 124A.

The natural levels of the Lake of the Woods, as derived by computation, receive confirmatory support from physical evidences of levels which prevailed before the construction of controlling works at the outlets, and from the testimony of persons, in both countries, who were familiar with the Lake of the Woods, even prior to 1887. The report of Special Agent A. F. Naff (see Appendix), made in December, 1895, and testimony taken at the Preliminary Lake of the Woods Hearings in September, 1912, both indicate that the levels which have prevailed during the past twenty-eight years are substantially above the levels which would have prevailed had no control been exercised.

Perhaps the best physical features which remain as evidence of prevailing natural levels on the Lake of the Woods are the winding channels still found in the estuary-like mouths of the streams running into the Lake. One of the best examples of such streams is Warroad River. (See Sheet No. 10 of Atlas.) The drainage area, tributary to this stream, is about 250 square miles. The ordinary spring flood-flow from this area is probably about 1500 c. f. s. The original channel of Warroad River, as indicated by soundings, is about 50 to 75 feet wide and 7 feet deep near its mouth. This cross-section would require a mean velocity of about 3 feet per second in order to carry the ordinary flood flow within its banks. At the lake stages which have prevailed during the past twenty-five years, at least, the lower reach of Warroad River has been a bay with almost no perceptible

THE DEVILS GAP NEAR KENORA

LOWER ASH RAPIDS—OUTLET OF SHOAL LAKE

UPPER ASH RAPIDS—OUTLET OF SHOAL LAKE

current. The winding channel of this River could not possibly have been cut and maintained under present prevailing lake stages. Under natural conditions, however, the level which prevailed in spring must have been sufficiently low to permit the maintenance of a good current in the River, and thus to keep the channel open, except for such silting at the mouth as would take place later in the season when the low water flow became very small or at times when the lake level being high would itself retard the flow.

In order, graphically, to summarize the data and computations relating to the levels of Lake of the Woods, the "Frequency Curves showing Actual Controlled Levels and Outflow, and Computed Natural Levels and Outflow," Plate 125, have been prepared. The curves are based on the records of the 23 years from 1893 to 1915, inclusive, and are believed to be fairly representative of the general meteorological phenomena appertaining to the watershed—although not necessarily representative of all extremes falling outside the sphere of our study.

It will be noted from the curve of Plate 125 that the level of the Lake of the Woods during this 23-year period was for 50 per cent of the time above a stage of 1060.00; and that the corresponding level which, according to our computations, would have prevailed if no control of the outflow from the Lake had been exercised, is 1056.60—a difference of 3.40 feet.

The average controlled level during the period under discussion is 1059.75, and the average computed natural level is 1056.71—a difference of 3.04 feet.

The curves of Plate 125 show further, that the extreme high actual mean monthly level is 1062.27, as contrasted with a computed high natural mean monthly level of 1061.02—a difference of 1.25 feet.

The lowest actual mean monthly level between 1893 and 1915 is 1056.64; whereas the lowest computed natural level is 1052.95—a difference of 3.69 feet.

For 10 per cent of the time in a state of nature the Lake rose above the stage of 1059.10; and for 5 per cent of the time the stage was above 1059.90, or practically above 1060.00.

A level of 1060 prevailing 5 per cent, or one-twentieth of the time, would be equivalent to about half a month for each year, or one month for every two years, or two and one-half months in five years. Between January 1st, 1893, and December 31st, 1915, there are 276 months, and during this period, by actual count, the monthly mean computed natural level for the Lake of the Woods exceeded the stage of 1060 during eleven months. These eleven months consist of three nearly equal periods of about three months each during the summers of 1896, 1897, 1899, and for about two months during the exceptional winter of 1900–1901.

Since the winter of 1900–1901 a natural level of 1060, according to our computations, would not have been exceeded, consequently a stage of 1060 can hardly be considered as any frequently recurring natural phenomenon.

A level of 1059, under natural conditions, would have been exceeded for periods totalling nearly two and one-half years out of the twenty-three. These periods consist of over six months in 1897, and from two to seven months during each of the years 1896, 1899, 1900, 1901, and 1905.

The stage 1058 would have been exceeded fourteen times, or an aggregate of a little more than five years out of the twenty-three.

The curves of actual outflow on Plate 125 show the inevitable concomitant of controlled levels, namely, greatly fluctuating discharge. The outflow under actual control reached both higher and lower values than would have been reached from 1893 to 1915, under natural conditions. The natural outflow, as a matter of fact, would have been much more advantageous for water power developments on the Winnipeg River below the outlets of the Lake than was the outflow as actually controlled. It would also have been more favorable to the water powers at the outlets, if a larger portion of the total outflow from the Lake had normally been utilized, and if the smaller controlled outflow during low water periods had not been more than compensated for by the increased head resulting from a higher than natural lake level.

SUMMARY OF MONTHLY MEAN LAKE LEVELS

LAKE OF THE WOODS

(1893 to 1915)

Actual Controlled Levels				Computed Natural Levels			
Monthly Mean Lake Level	Number of Months			Monthly Mean Lake Level	Number of Months		
	Summer (May-Oct.)	Winter (Nov.-Apr.)	Total		Summer (May-Oct.)	Winter (Nov.-Apr.)	Total
1062.20-62.29		2	2	1061.00-61.09	1		1
62.10-62.19		1	1	60.80-60.89	1		1
62.00-62.09	5		5	60.70-60.79	1		1
61.90-61.99	3	1	4	60.60-60.69	1		1
61.80-61.89				60.50-60.59	1		1
61.70-61.79		2	2	60.40-60.49	2		2
61.60-61.69	4	1	5	60.30-60.39	1		1
61.50-61.59	1	1	2	60.10-60.19		1	1
61.00-61.49	23	8	31	60.00-60.09	1	1	2
60.50-60.99	26	16	42	59.50-59.99	7	1	8
60.00-60.49	26	25	51	59.00-59.49	7	4	11
59.50-59.99	14	14	28	58.50-58.99	7	4	11
59.00-59.49	12	12	24	58.00-58.49	15	8	23
58.50-58.99	11	14	25	57.50-57.99	17	8	25
58.00-58.49	4	8	12	57.00-57.49	14	13	27
57.90-57.99		5	5	56.50-56.99	11	15	26
57.80-57.89		2	2	56.00-56.49	19	21	40
57.70-57.79		1	1	55.50-55.99	10	16	26
57 60-57.69	1	1	2	55.00-55.49	9	18	27
57.50-57.59		1	1	54.50-54.99	4	12	16
57.40-57.49		4	4	54.40-54.49	1	2	3
57.30-57.39	2	3	5	54.10-54.29	1	3	4
57.20-57.29	2	2	4	53.70-53.79		1	1
57.10-57.19	1	4	5	53.60-53.69	1		1
57.00-57.09		2	2	53.50-53.59		1	1
56.90-56.99	2	2	4	53.40-53.49	2		2
56.80-56.89	1	3	4	53.30-53.39	3	1	4
56.70-56.79		2	2	53.20-53.29		1	1
56.60-56.69		1	1	53.10-53.19	1	3	4
				53.00-53.09		1	1
Total	138	138	276	52.90-52.99		3	3
				Total	138	138	276
Average Actual Controlled Lake Level=1059.75				Average Computed Natural Lake Level=1056.71			

SUMMARY OF ANNUAL RANGE OF LEVEL

LAKE OF THE WOODS

Year	High Water					Low Water					Yearly Fluctuation	
	Actual Controlled	Date	Computed Natural	Date	Difference in Feet	Actual Controlled	Date	Computed Natural	Date	Difference in Feet	Actual Controlled	Computed Natural
1893	1060.28	July 28	1059.00	Aug. 1	1.28	1057.31	Dec. 31	1055.88	Dec. 31	1.43	2.97	3.12
1894	60.48	July 15	58.89	July 21	1.59	56.55	Apr. 3	54.56	Apr. 11	1.99	3.93	4.33
1895	59.27	Aug. 3	57.55	Aug. 15	1.72	56.68	Apr. 5	54.70	Apr. 11	1.98	2.59	2.85
1896	62.15	July 4	60.71	July 11	1.44	56.72	Mar. 30	54.72	Apr. 1	2.00	5.43	5.99
1897	62.27	July 29	61.20	Aug. 1	1.07	58.17	Mar. 25	57.00	Mar. 25	1.17	4.10	4.20
1898	60.35	Dec. 15	58.53	Oct. 21	1.82	57.04	Apr. 24	55.71	May 11	1.33	3.31	2.82
1899	62.10	July 25	60.79	Aug. 11	1.31	59.54	Apr. 19	56.51	Apr. 21	3.03	2.56	4.28
1900	62.37	Nov. 23	60.16	Dec. 31	2.22	58.80	Apr. 18	54.98	Aug. 21	3.82	3.57	5.18
1901	62.04	Jan. 1	60.16	Jan. 1	1.88	59.55	Dec. 31	56.22	Dec. 31	3.33	2.49	3.94
1902	60.74	July 11	58.11	Aug. 1	2.63	59.00	Apr. 20	55.21	Apr. 21	3.79	1.74	2.90
1903	61.40	June 3	58.60	June 15	2.80	59.52	Dec. 31	55.99	Mar. 21	3.53	1.88	2.61
1904	60.63	July 21	57.56	July 21	3.07	58.54	Apr. 13	55.48	Apr. 11	3.06	2.09	2.08
1905	62.14	Aug. 24	59.95	Sept. 21	2.19	58.10	Apr. 19	54.98	Apr. 21	3.12	4.04	4.97
1906	61.59	Jan. 1	58.50	July 11	3.13	59.20	Dec. 31	56.05	Dec. 31	3.15	2.39	2.45
1907	62.15	Oct. 23	58.17	Oct. 21	3.98	58.60	Apr. 15	55.14	Apr. 21	3.46	3.55	3.03
1908	61.92	Jan. 1	58.23	July 11	3.69	59.80	Dec. 25	56.40	Dec. 31	3.40	2.12	1.83
1909	60.55	Dec. 31	56.40	Jan. 1	4.15	58.73	May 3	54.72	May 1	4.01	1.82	1.68
1910	61.55	Apr. 28	57.18	June 1	4.37	57.86	Dec. 31	53.63	Dec. 31	4.23	3.69	3.55
1911	57.85	Jan. 1	53.63	Jan. 1	4.22	56.84	Sept. 11	52.92	Apr. 11	3.92	1.01	0.71
1912	60.83	Nov. 3	55.72	Oct. 25	5.11	57.03	Jan. 1	52.88	Apr. 1	4.15	3.80	2.84
1913	61.15	May 15	56.02	Aug. 21	5.13	60.07	Oct. 1	54.29	Apr. 1	5.78	1.08	1.73
1914	61.39	June 17	56.52	Aug. 1	4.87	59.93	Apr. 10	54.07	Apr. 15	5.86	1.46	2.45
1915	61.83	June 27	56.97	Aug. 21	4.86	60.20	Nov. 10	54.58	Apr. 11	5.62	1.63	2.39
Average 1893 to 1915	1061.18	.....	1058.20	.....	2.98	1058.43	.....	1055.07	.....	3.35	2.75	3.13

NOTE: These elevations have been taken from the line of Mean Observed Lake Levels, as given on Plates 39 to 50, and from the line of Computed Natural Levels, as given on Plates 114 to 124A.

During the period from 1893 to 1915, inclusive, the following extreme levels have prevailed: The highest mean actual controlled level was 1062.37 on November 23rd, 1900. The lowest mean actual controlled level was 1056.55 on April 3rd, 1894. The extreme fluctuation in actual controlled levels was 5.82 feet. The highest mean computed natural level for the same period is 1061.20 on August 1st, 1897. The lowest mean computed natural level for the same period is 1052.88 on April 11th, 1912. The extreme fluctuation in computed natural levels is 8.32 feet.

SUMMARY OF ANNUAL RANGE OF OUTFLOW

LAKE OF THE WOODS

Year	High Water					Low Water					Yearly Fluctuation	
	Actual Controlled	Date	Computed Natural	Date	Difference in c. f. s.	Actual Controlled	Date	Computed Natural	Date	Difference in c. f. s.	Actual Controlled	Computed Natural
1893	25570	July	24190	Aug. 1	1380	10470	Dec	13080	Dec. 31	−2610	15100	11110
1894	27500	July	23650	July 21	3850	7105	Apr	9880	Apr. 11	−2775	20395	13770
1895	20500	July and Aug	18120	Aug. 15	2380	8360	Mar	10195	Apr. 11	−1835	12140	7925
1896	37730	July	33930	July 11	3800	7800	Mar	10240	Apr. 1	−2440	29930	23690
1897	38380	July and Aug	37175	Aug. 1	1205	13940	Mar	16270	Mar. 25	−2330	24440	20905
1898	23535	Oct	22000	Oct. 21	1535	10170	Nov. and Dec.	12640	May 11	−2470	13365	9360
1899	39705	July and Aug	34450	Aug. 11	5255	11575	Oct	14800	Apr. 21	−3225	28130	19650
1900	40380	Nov. and Dec	30520	Dec. 31	9860	8615	July and Aug.	10840	Aug. 21	−2225	31765	19680
1901	38600	Jan	30520	Jan. 1	8080	10350	Dec	13990	Dec. 31	−3640	28250	16530
1902	33440	July	20250	Aug. 1	13190	9630	Mar. and Apr.	11390	Apr. 21	−1760	23810	8860
1903	33440	May	22310	June 15	11130	12140	Apr	13370	Mar. 21	−1230	21300	8940
1904	22655	Nov	18160	July 21	4495	11015	Dec	12050	Apr. 11	−1035	11640	6110
1905	39260	Aug. and Sept	29275	Sept. 21	9985	10635	Mar	10840	Apr. 21	− 205	28625	18435
1906	30520	Apr. and May	21870	July 11	8650	10740	Dec	13530	Dec. 31	−2790	19780	8340
1907	20820	Oct. and Nov	20090	Oct. 21	730	9260	May	11230	Apr. 21	−1970	11560	8860
1908	27110	June	20730	July 11	6380	8900	Dec	14490	Dec. 31	−5590	18210	6240
1909	11150	Aug and Sept	14490	Jan. 1	−3340	7990	Apr	10240	May 1	−2250	3160	4250
1910	27900	Apr. and May	16850	June 1	11050	6500	Dec	7960	Dec. 31	−1460	21400	8890
1911	8620	June, Jan., July	7960	Jan. 1	660	3170	Dec	6720	Apr. 11	−3550	5450	1240
1912	10430	Oct., Nov., Dec	12660	Oct. 25	−2230	3255	Jan	6660	Apr. 11	−3405	7175	6000
1913	20340	June	13450	Aug. 21	6890	4520	Apr	9300	Apr. 1	−4780	15820	4145
1914	20660	July	14830	Aug. 1	5830	6670	Feb	8840	Apr. 15	−2170	13990	5990
1915	25760	July	16170	Aug. 21	9590	7580	Dec	9930	Apr. 11	−2350	18180	6240
Average 1893 to 1915	27131		21898		5233	8713		11238		−2526	18418	10659

NOTE: The actual controlled rates of outflow have been taken from Table 70 of the Volume of Tables. The computed natural rates of outflow are those which, according to Table 93 of the Volume of Tables, corresponds to the highest and the lowest computed natural lake levels. During the period from 1893 to 1915, inclusive, the following extreme rates of outflow have prevailed:

The highest actual controlled daily rate of outflow was 40,380 c. f. s. in November and December, 1900.
The lowest actual controlled daily rate of outflow was 3170 c. f. s. in December, 1911.
The extreme fluctuation in observed daily rate of outflow was 37,210 c. f. s.
The highest computed natural rate of outflow during the same period is 37,175 c. f. s. on August 1st, 1897
The lowest computed natural rate of outflow during the same period is 6660 c. f. s. on April 11th, 1912
The extreme fluctuation in computed natural rates of outflow is 30,515 c. f. s.

RUNOFF FROM UPPER RAINY WATERSHED, 1905 TO DATE

The available continuous records of water levels in Rainy Lake and records of outflow from the Lake, are limited to the period from August, 1911, to date. It is possible, however, on the basis of various, more or less fragmentary and incomplete data, gathered for earlier years to extend these records of lake stage and outflow, and thereby to secure substantially correct values of runoff for the period from October, 1905, to date.

The following records of lake stages, records of water levels above and below Koochiching Falls, records of head water and of tail water levels, discharge measurements, and records of flow through the power plant at Fort Frances and International Falls, are available:—

1. Records of H. I. Mortimer and S. Hazlewood, Engineers associated with the early surveys for the Canadian Pacific Railway Company:
   Determination of fall of 23′ 4″ at Koochiching Falls in autumn of 1874.
   Determination of fall of 13″ at upper rapids at outlet of Lake, and 11″ at lower rapids, in autumn of 1874.
   Determination of fall of 12″ at rapids at outlet of Lake and 10″ at lower rapids taken as far as can be determined, in the summer of 1875.
2. Record of L. A. Ogaard, County Surveyor, International Falls, Minn:
   Determination of total fall of 2 feet at rapids at outlet of Lake in spring of 1895 and soundings on cross section of channel above Falls.
3. Records of J. T. and R. B. Fanning, Engineers for the Minnesota & Ontario Power Company:
   Float measurement of discharge of Rainy River at Fort Frances and International Falls, made September 5th, 1900, giving 3431 c. f. s.
   Determination of fall between Rainy Lake and the River below Pithers Rapids by wye level on September 9th, 1900, giving .41 foot fall at the upper rapids and .66 foot fall at the lower rapids.
   Water levels observed near the head of the Canadian navigation canal as follows:
      September 3rd, at 4:48 p. m., water level 486.718
      September 4th, at 1:30 p. m., water level 486.772
      September 11th, at 2:00 p. m., water level 487.507
4. Records of E. B. Banks, Engineer for the Minnesota Canal & Power Company:
   Profile showing water-ways connecting Birch Lake in Lake County, Minnesota, with the Lake of the Woods, dated July 1904, on which are given the following elevations relating to Rainy Lake and Rainy River:
      Extreme high water in Lake 496.44
      Ordinary high water in Lake 494.44
      Extreme low water in Lake 489.00
   Water levels observed at time of survey:

In Rainy Lake	492.50
Below Upper Rapids	491.60
Below Lower Rapids	490.70
Above Falls	490.60
Below Falls	467.20

Courtesy of Mr. Bruce Lloyd

KOOCHICHING FALLS

(SITE OF PRESENT POWER DEVELOPMENT AT FORT FRANCES AND INTERNATIONAL FALLS)

PLATE MM

5. Records of the Ontario Hydro-Electric Power Commission:
   Water levels above Koochiching Falls, observed at Fort Frances, Ontario, from October, 1905, to October, 1906. Table 38. Plate 87.
   Discharge measurements of Rainy River at old meter section below Koochiching Falls, on October 25th, 1905, April 1st, 1906, and September 27th, 1910. Table 61.
6. Records of the Canadian Northern Railway Company:
   Water levels observed in Rainy Lake as follows—
   February 1909, 1099.60 Sea-level Datum or 487.99 Public Works Datum
   January 1910, 1108.11 Sea-level Datum or 496.50 Public Works Datum
   February 1913, 1105.13 Sea-level Datum or 493.52 Public Works Datum
7. Records of Minnesota & Ontario Power Company:
   Water levels above and below Koochiching Falls, and, at later date, above and below the Company's power plant, observed at International Falls and Fort Frances, from March, 1907, to date, and occasional Lake levels observed at Ranier, Minnesota, during 1908, 1910, and 1911. Table 36. Plates 88 to 97.
   Discharge measurements of Rainy River below Koochiching Falls, June 14, 1904, September 21, 1908, and October 10, 1908. Table 61.
   Monthly estimates of discharge, power, water wasted, etc., at the Company's power plant, from September, 1910, to date. Table 90.
8. Records of United States Geological Survey:
   Water levels at U. S. Dock, observed at International Falls, Minnesota, from April, 1911, to August, 1914. Table 37.
   Discharge measurements, Rainy River, at International Falls, Minnesota, between September, 1909, and August, 1912. Table 61.
9. Records of Department of Public Works, Canada:
   Water levels in Rainy Lake observed at Ranier, Minnesota, from August, 1911, to date. Table 31. Plates 90 to 92.
   Water levels above and below the Minnesota & Ontario Power Company's plant, observed at Fort Frances, Ontario, from August, 1911, to date. Tables 33 and 34. Plates 90 to 92 and 95 to 97.
   Water levels at U. S. Dock, observed at International Falls, Minnesota, from August, 1911, to date. Table 35. Plates 95 to 97.
   Discharge measurements, Rainy River at Fort Frances and International Falls, from May, 1911, to date. Table 61.
   Records of daily discharge based on discharge measurements, power output of the Minnesota & Ontario Power Company's plant, gate openings, head, etc., from August, 1911, to date. Table 75.
10. Records of Manitoba Hydrographic Survey:
    Discharge measurements of Rainy River at Fort Frances and International Falls, between August, 1912, and January, 1913. Table 61.
11. Records of International Joint Commission:
    Discharge measurements of Rainy River at International Falls and Fort Frances during 1913. Table 61.

Practically continuous readings of water levels in the Rainy River below Koochiching Falls, at the site of the present dam and power plants at International Falls and Fort Frances, a general plan of which is shown on Plate 84, followed by readings of the tail water gauge at the plant, are available from March 1st, 1907, to date. If a constant relationship existed, at this point, between stage and discharge, accurate records of outflow would become available upon

rating the tail water gauge. The river bottom at this point is perfectly stable, and the channel is not subject to shifts, but the lodging of ice on the Manitou Rapids and the flood flows from the Little Fork and the Big Fork Rivers, however, produce considerable backwater below the power plant for months at a time, so as to completely nullify the normal relationship between stage and discharge.

This normal relationship between water level in the Rainy River at the U. S. Dock in International Falls, and discharge of the stream, is shown graphically on Plate 85. All available measurements which have been made of the discharge of the Rainy River at International Falls and Fort Frances, and upon which this rating curve of discharge is based, are assembled in Table 61. When plotted, the measurements which were made when backwater prevailed lie considerably above the discharge curve shown on Plate 85, and, besides, the mean velocity at the time of such measurements was considerably less than the normal velocity at the given stage. This curve of Plate 85 may be used to determine discharge from observed tail water levels whenever the River is free from backwater.

From October 25th, 1905, to October, 28th, 1906, and from March 1st, 1907, to March 10th, 1909, when control began to be exercised, at the power plant, over the flow of the River, readings were taken of a gauge located above the Falls. From October 28, 1906, to March 1, 1907, the water levels for "Above the Falls" were taken from an estimated smooth curve shown on the graphs. After determining the relationship between water level above the Falls and discharge, as shown on Plate 83, values of daily discharge were derived from this relationship for the above mentioned period. In deducing such a curve of relationship for all stages, however, considerable difficulty was experienced because the available data, if accepted at their face value, indicated changes at the Falls prior to 1907, which affected the discharge capacity of the channel at that point, particularly at low water.

The "Above Falls" rating curve, adopted for the period covered by the "Above Falls" readings from October, 1905, to July, 1906, is based, principally, on the discharge measurement and the water level above the Falls, obtained by Messrs. J. T. and R. B. Fanning, during the extreme low water of September 5th, 1900, and similar data obtained by Mr. H. G. Acres for the Ontario Hydro-Electric Power Commission on October 25th, 1905, and April 1st, 1906, at stages above the Falls of 491.75 and 488.5, respectively.

For obtaining discharge values during the fall and winter of 1906–1907 and to October, 1908, the 1906–1908 portion of the rating curve was adopted. This curve is based on a large number of consistent gauge readings, three discharge measurements made by the

Courtesy of Mr. E. W. Backus

KOOCHICHING FALLS
(DETAIL OF MAIN FALL)

Courtesy of Mr. C. J. Rockwood

KOOCHICHING FALLS IN HIGH WATER

Courtesy of Mr. R. B. Fanning

TONGUE OF ROCK EXTENDING INTO RAINY RIVER ABOVE KOOCHICHING FALLS FROM UNITED STATES SIDE, IN STATE OF NATURE

Courtesy of Mr. R. B. Fanning

INTERNATIONAL FALLS—FORT FRANCES DAM UNDER CONSTRUCTION

CAVING BANKS AT FORT FRANCES

Minnesota & Ontario Power Company, and the open water rating of the lower gauge. Apparently the discharge capacity of the channel above the Falls had increased prior to March, 1907, when the Minnesota & Ontario Power Company began its readings.

During the winter of 1908–1909 further changes in discharge capacity seem to have been made. Conditions at this time are represented by the broken line curve marked "1908–1909."

The daily discharge of the Rainy River at International Falls and Fort Frances, between October 25th, 1905, and March 10th, 1909, is, then, determined from the several ratings of the "Above Falls" gauge, as indicated above.

In analyzing the available records of stage and discharge and in making computations intended to verify, disprove, or co-ordinate the various available records, and to establish the rating curves of Plate 83, extensive use was made of the hydrographic map of Pither's Rapids, Plate 77, based on data furnished by the Department of Public Works, Canada, of the map of Koochiching Falls in a state of nature, Plate 76, compiled from various sources as indicated, and of the cross sections of the channel shown on Plates 78 and 79.

The photographs of Koochiching Falls in a state of nature and during the construction of the Power Dam, shown on Plates MM, NN, OO, PP, and QQ, together with a large number of unpublished photographs were also of great assistance.

Although the data upon which these curves of Plate 83 are based are not as complete as might be desired, our conclusions are believed to be well founded, and the probable error involved can not be of sufficient magnitude to substantially change any conclusions arrived at with respect to run-off from the Upper Rainy watershed.

The daily discharge for the Rainy River is given in Table 75, and in order to show the extent to which backwater occurs at this portion of the Rainy River, the tail water level at the U. S. gauge, corresponding to the daily discharge, is plotted on the graphs of observed tail water levels beginning March 1st, 1907. The rise in tail water, of about 2 feet, on December 1st, 1908, due to ice formation as the result of a sudden drop in temperature, is particularly noticeable. This amount of backwater prevailed with little change, throughout the winter, in fact until it was replaced by backwater due to flood flows from the tributaries of the Lower Rainy during the spring break-up.

It appears from the graphs and the following table, that the Rainy River at International Falls and Fort Frances is subject to the equivalent of a little more than 2 feet of backwater for six months of the year.

Backwater in Rainy River at Lower Gauge—International Falls and Fort Frances

(Quantities are in Feet.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1907	.....	.....	1.03	0.49	1.86	0.22	.....	.....	.....	.....	.....	1.32
1908	2.27	2.31	1.59	1.23	3.07	1.87	0.23	.....	.....	.....	.....	1.85
1909	1.83	2.22	1.50	0.64	.....	.....	.....	.....	0.43	0.43	.....	1.43
1910	1.75	1.62	0.91	0.55	.....	.....	.....	.....	.....	.....	0.53	1.55
1911	1.95	2.13	2.14	1.43	.....	0.32	.....	.....	.....	.....	0.90	1.01
1912	1.64	1.69	1.22	0.44	0.85	.....	.....	.....	.....	.....	.....	1.37
1913	1.59	2.04	1.77	1.40	1.43	1.38	0.98	0.43	.....	0.78	0.33	1.38
1914	1.46	1.88	0.99	0.78	2.52	0.88	0.54	.....	.....	.....	0.32	0.67
Average	1.78	1.98	1.39	0.87	1.95	0.93	0.58	0.45	.....	0.60	0.52	1.32

The curve of Plate 83, showing relation between water level in Rainy Lake and outflow from the Lake, is even less well defined than the curve showing the relation between water level above the Falls, and discharge. We believe, however, that this curve is fairly consistent with the data which have been available.

The earliest records, which we have been able to find, of fall between Rainy Lake and the pool above Koochiching Falls are those obtained from various statements respecting early surveys made in connection with proposed routes for the Canadian Pacific Railway. It appears that in the fall of 1874, Mr. H. I. Mortimer, a civil engineer, associated with the early survey work of this railway, while examining part of the Dawson route, determined the fall at the upper rapids at the outlet of Rainy Lake to be 1 foot 1 inch, and the fall at the lower rapids to be 11 inches. He also determined the fall at Koochiching Falls to be 23 feet 4 inches. Mortimer's statements dealing with this matter, under date of January 28th, 1875, are as follows:

"This portage" (around Koochiching Falls at Fort Frances, Ontario) "is on the Rainy River; the length is 470 feet, the difference in line of the waters 23 feet 4 inches.

"Five miles * above Fort Frances, at the entrance of Rainy Lake, are two rapids, the lower of 11-inch fall, the upper of 1 foot 1 inch. The Rainy Lake steamer does not run below these rapids, freight and passengers being carried in boats, which are hauled up into the lake and then transferred to the steamer. Mr. Fowler, of the Fort Frances saw mill, informed me that he intended extending his dam further across the falls this winter; this, with a double boom from this Island to a pier in the river, would so contract the water discharge as to raise Rainy River to the level of Rainy Lake, or sufficiently to allow the passage of the steamer from Fort Frances to Kettle Falls; this distance is called forty-five miles."

With respect to the contemplated improvement of navigation through the extension of the existing "dam" at Fort Frances, Mortimer wrote on July 1st, 1875, as follows:

"A contract was given . . . last winter to construct certain crib work in the channel of the river immediately above the falls. So much of the work has been

* One is surprised to find "Five miles" given as the distance from Fort Frances to the Rapids at the outlet of Rainy Lake, particularly in view of the fact that Mortimer's other statements as to length of portages are accurate. (Consulting Engineers.)

completed as to produce the desired effect and the steamer now runs up and down the rapids at the outlet of Rainy Lake."

Further information relating to this subject is contained in the correspondence of Mr. S. Hazlewood, apparently an engineer in charge of work being performed under the direction of Mr. Mortimer under date of August 28th, 1875.

"It will be observed that the course of a vessel making for the mouth of the canal will be in comparatively still water.

"The difference of level between the surface of water at the head of the proposed Locks, and the surface of water at the foot thereof is 23 feet 4 inches, and the difference of level between the surface of water in Rainy Lake, and the foot of the proposed Locks, is 25 feet 6 inches, there being a fall of 2 feet 2 inches between Rainy Lake, and the head of the proposed Canal. This fall occurs in three places in Rainy River, the first is at the outlet of the Lake, where there is a fall of 12 inches.

"About ½ of a mile below this there is a fall of 10 inches, the remaining 4 inches is due to the fall in the River, to the head of the Locks, a distance of about two miles.

"The fall at the outlet of the Lake is divided into two channels by an Island, that on the West or Canadian side of the island being the route for canoes, and the channel on the East side of the island, is the main or steam-boat channel.

"The fall here consists simply of swift water, and should offer no impediment to the navigation of the River at all stages of the water, provided steamers of proper construction for such work were employed.

"The second rapid ½ of a mile down from the outlet of the Lake is navigable during high and ordinary water, but during the period of low water from about 1st of August to the close of the season, the navigation is somewhat obstructed by the presence of boulders, which can easily be removed during the winter season."

The essence of the information furnished by these engineers is that the fall at the outlet of Rainy Lake, determined by Mortimer in 1874, was 2 feet, consisting of 13 inches at the Upper Rapids and 11 inches at the Lower Rapids; that the fall at the outlet, determined by Hazlewood in 1875, was 1 foot 10 inches, consisting of 12 inches at the Upper Rapids and 10 inches at the Lower Rapids, in addition to the fall of 4 inches in the river between the Lake and the pool above the main Falls.

The bench mark to which these observations were referred has been lost, and consequently the lake level prevailing at that time is not known in terms either of Public Works or Sea-level Datum. The fall at Koochiching Falls as recorded by Hazlewood in October, 1875, is 23.92 feet, and was measured after the extension of the crib work or "dam" at Fort Frances, which is supposed to have made the river navigable at Pithers Rapids. We are inclined to believe, however, that the construction of the crib work at the saw mills did not materially affect the natural outflow capacity of the Lake, or the fall between the Lake and the Falls.

The next record of fall between Rainy Lake and the pool above Koochiching Falls, which we have been able to obtain, is that made by Mr. L. A. Ogaard, County Surveyor, International Falls, Minn.,

in the early spring of 1895, giving an even 2 feet of total fall through the two rapids at the outlet of the Lake, in low water. Mr. Ogaard has stated that he has a definite recollection of making the measurement with a wye level and that the fall was an even two feet.

On September 9th, during the low water of 1900, Messrs J. T. and R. B. Fanning determined a fall of 1.07 feet through the rapids at the outlet of the Lake, consisting of .41 foot at the upper rapids and .66 foot at the lower rapids. Mr. R. B. Fanning has stated that a good wye level was used in determining this fall.

The next record of fall at the outlet of the Lake is that of 1.8 feet, given on the profile of Mr. E. B. Banks, engineer for the Minnesota Canal & Power Company, dated July 1904. The stage at which Mr. Banks made his measurement appears to have corresponded to a discharge of about 12,000 c. f. s.

Further observations of fall have been secured from the records of the Minnesota & Ontario Power Company. Readings taken by Mr. H. C. Ash, one of the Company's engineers, on the gauge above the Falls, and on the gauge in the Lake, give a total fall between the Lake and the pool above the Falls, on September 21st, 1908, of 1.7 feet at a measured rate of discharge of 12,170 c. f. s. Readings taken by Mr. Ash on October 10th, 1908, give a fall of 1.5 feet between the Lake and the pool above the Falls at a measured discharge of 11,270 c. f. s. In plotting these values of fall on Plate 83, the mean discharge taken off the curve for the given water level above the Falls has been used.

The only additional record of a measurement of fall made previous to the time at which control commenced at the power plant, consists of a lake level of 488.0, determined by the Canadian Northern Railway in February, 1909, and an average stage above the Falls for the same month, according to the records of the Minnesota & Ontario Power Company, of about 486.4, giving a fall of 1.6 feet between the Lake and the Falls at a low water stage of about 4000 c. f. s.

It might also be noted that on Page 172 of the Report on Geological and Natural History Survey of Minnesota, Volume 4, 1896–1898, the fall from Rainy Lake to below the second rapids, at the outlet of the Lake, is given as 3 feet, and the fall in the river between the Lake and the head of Koochiching Falls is given as 1 foot. The fall at Koochiching Falls itself is given as 23 feet, with a footnote as follows:

"By leveling by L. A. Ogaard for the Koochiching Company this fall was found to be 21 feet in high water and 24½ feet in low water."

Inasmuch as no stage is recorded for the Lake, and the fall is given merely in even feet, this record may be considered as merely

confirming, in a general way, other evidence indicating considerable fall between the Lake and the head of Koochiching Falls in a state of nature. The record of Fanning, which was taken at an unusually low stage, is the single record indicating only about 1 foot of fall at the rapids at the outlet of the Lake, in low water, and if accepted as correct, indicates either a marked low water control section at the crest of the Falls, or a reduction in the discharge capacity of the channel at the Falls, between 1895 and 1900.

Since, however, the lower portions of these curves of Plate 83 are not used in determining outflow, it follows that the uncertainties involved are of no consequence in that respect. They are, however, of importance in connection with the determination of low lake stages in a state of nature, and to some extent also in the determination of high lake stages under natural conditions.

Before discussing the method used in ascertaining discharge for the period between March 10th, 1909, and August 14th, 1911, when the Department of Public Works, Canada, began making estimates of flow through the power plants at Fort Frances and International Falls on the basis of gauge heights, power output, gate openings, etc., it is necessary to explain the curves of Plate 86. These curves are based upon records of discharge and records of water levels observed in Rainy Lake, and in the pool above the dam, during the period from August, 1911, to date. While the available data are to a certain extent conflicting, it is believed that the relationship between stage, fall, and discharge given by these curves is substantially correct, more particularly between the limits of the portions of the curves which have been employed in this report.

The use of these curves of Plate 86 may be illustrated as follows,— Assume an elevation of 490 for the water surface in the pool above the dam, and an elevation of 490.6 for the water surface in Rainy Lake. Entering the curves with an elevation of 490 at the dam and a fall of .6 foot from Lake to dam, the curves give a discharge of 4250 c. f. s. On the other hand, assume a discharge of 10,000 c. f. s. at a stage of 491.5 above the Falls, and a fall of 1.2 feet is obtained between the Lake and the dam. The rapidly increasing fall for increasing rate of discharge at low lake stages is at once apparent.

These curves of controlled outflow, stage and fall have been used, mainly, in computing levels for Rainy Lake between March, 1909, and August 14th, 1911, i. e., the period extending from the commencement of control at the Falls to the date after which observed Lake levels are available. The curves have also been of considerable assistance in determining outflow from Rainy Lake for the same period.

98896—17——14

The notes relating to construction operations at the dam during 1909, and having a bearing upon the outflow from the Lake during this period, are given at the end of Table 75.

An inspection of the graphs of water levels, Rainy River, Plates 89 and 94, indicates that on March 17th, 1909, the tail water level suddenly rose .8 foot, while the head water level fell 1.25 feet, and that on April 13th of the same year the tail water level fell 1.1 feet and the head water level rose .65 foot. Evidently such sudden and large changes in levels could have been produced only by great changes in the discharge capacity of the channel at the Falls. The sudden drop in head water level on March 17th was accompanied by a rise in tail water level, representing an increased discharge of about 1200 c. f. s. on the open water rating curve. Because of the existence of considerable backwater, however, the actual increase in discharge was considerably greater than the increase represented by the rise in water level at the gauge. According to the stage, fall, and discharge curves, Plate 86, this increase in discharge between March 16th and 19th amounted to about 1600 c. f. s., which is the value adopted, and which corresponds to the rise shown in the line of mean tail water level at the U. S. gauge, corrected for backwater.

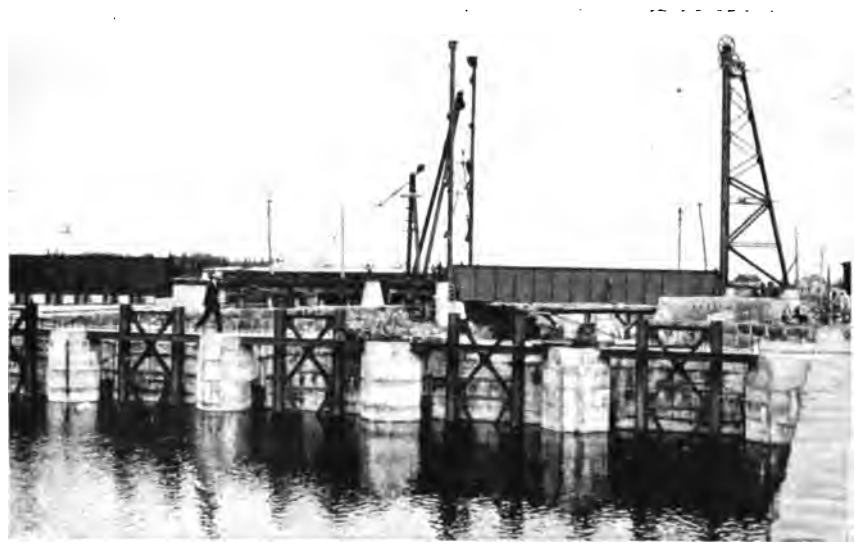
According to notes obtained from records of the Minnesota and Ontario Power Company, the waste gates were closed on May 6th, 1909, in order to hold the water. In view of the fact that the records of the upper gauge show no appreciable rise in head water from May 6th to May 7th, there can have been no great difference between water level at the upper gauge and the water level in the Lake, before the closing of the gates. This substantiates our conclusion, as indicated by the computed lake level line on the graph of observed water levels for 1909. With a closing of the waste gates, the discharge from May 6th to 29th must have been reduced to leakage, which we have assumed as amounting to 300 c. f. s.

Meteorological records indicate that the sudden and large rise in tail water level during May was entirely due to floods on the Little Fork and the Big Fork Rivers. The Minnesota & Ontario Power Company records indicate that on May 27th and 28th the log sluice and the waste gates were again opened, consequently there would be a large increase in discharge at this time, as indicated by the observed tail water levels. Corrections for backwater due to heavy discharge from the Little Fork and the Big Fork Rivers, were made in August, October, and November, 1909. Two meter measurements made during this year also check the line of mean tail water level adopted.

The discharge between December, 1909, and March, 1910, is based principally upon the lowest observed tail water level on March 23rd,

Courtesy of Mr. C. J. Rockwood

CANADIAN CANAL EXCAVATION AT FORT FRANCES PRIOR TO CONSTRUCTION OF POWER DAM



SLUICE GATES AT HEAD OF CANADIAN CANAL—FORT FRANCES—1913

1910. Meteorological data indicate that on this date backwater, due to ice, had just subsided, and backwater, due to floods on the tributaries of the Lower Rainy, had not yet appeared. Assuming, then, that the gauge height on March 23rd, 1910 (when reduced by .2 foot for the average fall between the lower Minnesota & Ontario Power Company's gauge and the gauge on the U. S. Dock), correctly represented the discharge on that date, the discharge during the winter is based upon the fact that no change in the waste gates at the dam is recorded, and that, consequently, the discharge would vary during the winter approximately as the square root of the head on the gate openings. Extending this line backward to December 6th, we find it intersecting the line of observed tail water levels at the time when a large drop in temperature occurred, and backwater, due to ice, similar to that which prevailed in December, 1908, would again be expected.

The discharge between March 23rd and November 20th, 1910, is based upon the open water rating of the tail water gauge and several discharge measurements, together with meteorological data indicating flood flows in the latter part of March and in April, 1910, from the Little Fork and the Big Fork Rivers.

Beginning in September, 1910, the Minnesota & Ontario Power Company commenced making estimates of the amount of water discharged at the dam, on the basis of power output, head, gate openings, etc. If these estimates of discharge during September and October, 1910, and May, July, August and September, 1911,—being months during which the river was free from backwater—are compared with the average discharges for these same months as determined by means of the open rating curve, we find that the mean of the latter is 118% of the mean discharge computed by the Minnesota & Ontario Power Company. Assuming that this same relation holds during the winter months of November, 1910, to April, 1911, the monthly mean discharge is then ascertainable from the Minnesota & Ontario Power Company's estimates, by multiplying them by 1.18. This has been done and from the monthly mean discharge values, the corresponding monthly mean tail water stages have been obtained. From these, in turn, have been deduced estimates of monthly average backwater, extending over the period from November, 1910, to April, 1911.

The detailed data relating to this estimate of backwater during the winter of 1910 to 1911 are given in the following table:

DATA RELATING TO ESTIMATE OF BACKWATER—RAINY RIVER AT INTERNATIONAL FALLS AND FORT FRANCES—WINTER OF 1910-1911

Date	Monthly Mean Tail Water* U. S. Dock	Discharge c. f. s.		Ratio Met. Sec. to Power House	119% of Power House	Equivalent Gauge Height U. S. Dock	Backwater Feet
		Meter Section	Power House (original estimate)				
Sept. 1910	462.25	5090	4212	1.19	.....	.....	.....
Oct. 1910	462.53	5420	4775	1.14	.....	.....	.....
Nov. 1910	463.29	.....	4928	.....	5820	462.81	[1] 0.48
Dec. 1910	463.04	.....	3598	.....	4220	461.59	[1] 1.45
Jan. 1911	462.17	.....	2385	.....	2800	460.22	[2] 1.95
Feb. 1911	462.01	.....	1976	.....	2330	459.67	[3] 2.34
Mar. 1911	462.13	.....	2158	.....	2540	459.92	[4] 2.21
Apr. 1911	461.43	.....	2047	.....	2420	459.77	[4] 1.66
May 1911	462.06	4785	3826	1.25	.....	.....	.....
June 1911 [5]	.....	.....	.....	.....	.....	.....	.....
July 1911	461.51	4130	3375	1.22	.....	.....	.....
Aug. 1911	463.23	6450	5687	1.14	.....	.....	.....
Sept. 1911	463.00	6100	5265	1.16	.....	.....	.....
Average	.....	.....	.....	1.18	.....	.....	.....

* These monthly means are obtained by subtracting 0.20 from the M. & O. values, in order to obtain level at U. S. Dock.

Since this portion of the report was completed a revised estimate of horsepower, discharge, waste, etc., has been received from the M. & O. Power Company. This revised estimate gives values of discharge slightly higher than the original. See Table 90.

[1] Beginning with November 20th, 1.5 feet was used for backwater effect through November and December. 1.5 ft. for approximately one-third month equals average of 0.5 ft. as against .48 ft. above. M. & O. records from Nov. 20 to Dec. 31 were corrected for 1.5 ft. plus 0.2 ft., or 1.7 feet.

[2] January M. & O. records were corrected for 2.00 ft plus 0.2 ft., or 2.2 feet.

[3] February M. & O. records were corrected for 2.20 ft. plus 0.2 ft, or 2.4 feet.

[4] An estimated value of 460.00 for effective tail water at U. S. Dock is used between February 14th and 24th, also between March 7th and April 30th, 1911.

[5] Not used in computations on account of backwater during month.

Except for a short period of backwater in June, 1911, the discharge from May 1st to August 14th, 1911, is determined from the open water rating curve and from a number of discharge measurements.

From August 14th, 1911, to date, the daily discharge records employed by us have been furnished by the Department of Public Works, Canada, based on discharge measurements, power output of the Minnesota & Ontario Power Company's plant, gate openings, head, etc.

Briefly, then, the table of daily discharge from October 25th, 1905, to December 31st, 1914, has been compiled as follows:

From October 25th, 1905, to March 10th, 1909, the discharges were obtained from the several rating curves shown on Plate 83 and the "Above Falls" gauge heights given in Table 36.

From March 10th, 1909, to August 14th, 1911, the discharges were obtained from the tail water rating curve shown on Plate 85 and the gauge heights given in Table 36, these being, where necessary, corrected for backwater as explained in detail in the foregoing pages.

Courtesy of Mr. E. W. Backus

PANORAMIC VIEW OF KOOCHICHING FALLS IN STATE OF NATURE
(CANADIAN CANAL EXCAVATION AT LEFT)

Photo by I. P. & I. Co.

PANORAMIC VIEW OF RAINY RIVER AT INTERNATIONAL FALLS AND FORT FRANCES
AFTER CONSTRUCTION OF POWER DAM.

PLATE QQ

From August 14th, 1911, to December 31st, 1915, the values are those furnished by the Department of Public Works, Canada.

Having determined the runoff from the Upper Rainy watershed, in other words, having determined the inflow into Rainy Lake, as given in Table 76, it becomes possible to construct a mass curve of runoff, as will be explained later, from which the controlled outflow under certain methods of regulation, and with certain amounts of available storage, can be ascertained. This controlled outflow from Rainy Lake can then be combined, tentatively, with the runoff from the Lower Rainy watershed, and with the runoff from the watershed of the Lake of the Woods, Proper, in order to derive the inflow into the Lake of the Woods under various methods of regulation of outflow from Rainy Lake.

RUNOFF FROM UPPER RAINY WATERSHED PRIOR TO 1905

The available records of water levels, discharge measurements, and other hydrographic data, have made it possible to deduce, with a considerable degree of accuracy, the runoff from the Upper Rainy watershed,—i. e., the watershed of the Lake of the Woods tributary to the Rainy River, at International Falls and Fort Frances,—between November, 1905, and December, 1915. Similar data have made it possible to obtain equally satisfactory runoff data for the entire watershed tributary to the Lake of the Woods for the period from October, 1892, to date.

In considering any future regulation of the level of the Lake of the Woods, the probable future rates of inflow into that Lake must be considered rather than the rates of inflow which prevailed in a state of nature. The rates of inflow into the Lake of the Woods, for the greater portion of each year, depend largely upon the rates of outflow from Rainy Lake, inasmuch as over half of the total Lake of the Woods watershed is virtually controlled by Rainy Lake. Out of the entire period of 23 years over which determinations of inflow into the Lake of the Woods extend, only 7 years cover a period of controlled outflow from Rainy Lake. The rates of outflow which have prevailed during the past seven years, however, will be considerably modified in the future, because, since the Canadian Paper Mill at Fort Frances was put into operation in 1914, a considerably larger quantity of water is required to operate the turbines on both sides of the river. In order to permit any studies to be made of the practicability and desirability of regulating the levels of the Lake of the Woods, estimates must be made of the probable rates of outflow from Rainy Lake which would have prevailed between 1892 and 1915, under such control of outflow as will probably be exercised at the outlet of Rainy Lake in the future.

In making a study of the probable outflow from Rainy Lake under the conditions of control which may prevail in the future, it is necessary, first of all, to apportion the observed runoff from the entire watershed tributary to the Lake of the Woods, between the Upper Rainy watershed and that below International Falls and Fort Frances.

While such an apportionment involves the possibility of error, it is well to have in mind that whatever error may be made in such estimates of distribution of runoff, will be practically lost before the Lake of the Woods itself is reached, because of the equalizing influence of the large storage capacity of Rainy Lake, and because of the fact that when the computed outflow from Rainy Lake is re-combined

with the runoff from the Lower Rainy watershed and the watershed of the Lake of the Woods, Proper, the sum total will again be equal to the observed inflow into the Lake of the Woods during the period over which estimates were made. The only error which is involved is that of the exact distribution of a certain given amount of runoff between the twelve months of the year. In other words, the error is not cumulative; the monthly values of total inflow into the Lake of the Woods remain as observed.

The runoff from the Upper Rainy Watershed, between 1892 and 1905, was computed on the basis of the analytical method described by Mr. Meyer in his recent paper on "Computing Runoff from Rainfall and other Physical Data," published in the Proceedings of the American Society of Civil Engineers, in March, 1915. Determinations of runoff have also been made from estimates of outflow from Rainy Lake for the years 1892 to 1905. These latter have been obtained by a largely graphical method, presented herewith on Plate 106, and based primarily upon the relationship existing between the observed outflow from this Lake during the period of years from 1905 to date, and the observed net inflow into the Lake of the Woods.

Having determined the curve of outflow, Plate 106, the monthly mean lake levels corresponding to these monthly mean rates of outflow are determined from the rating curve of outflow from Rainy Lake in a state of nature, and the curve of lake levels plotted. The lake level on the first of each month is then taken off from this curve, and the corresponding change in storage, representing either an increase in storage on the Lake or a draft on previous storage, added to or subtracted from the observed rates of outflow, to give the monthly runoff from the Upper Rainy watershed. These curves of runoff served primarily as a check, and, further, as a guide in determining the curve of natural outflow, i. e., the two operations were carried on virtually simultaneously.

The values given by the two methods agree very well, and contribute assurance to the accuracy of the result.

The curves of Plate 106 present the following information:

1st. The estimated average monthly precipitation and monthly mean temperature for the three watershed subdivisions.

2nd. The observed runoff from the entire Lake of the Woods watershed in inches depth on the watershed, per month.

3rd. The outflow from Rainy Lake, reduced to the equivalent inflow into the Lake of the Woods, in inches depth over the entire watershed of the Lake of the Woods.

4th. The monthly mean levels of Rainy Lake corresponding to the above monthly mean rates of outflow, according to the rating curve of outflow, Plate 83.

5th. The monthly runoff from the Upper Rainy watershed reduced to its equivalent in inches depth over the entire watershed

of the Lake of the Woods, derived by combining outflow with storage, and plotted to the same scale as the curves of observed runoff from the entire Lake of the Woods watershed, and the curve of outflow from Rainy Lake, for the purpose of securing a ready graphical comparison between these three curves.

A study of the discharge of the Little Fork and the Big Fork Rivers, which may be regarded as streams typical of the Lower Rainy watershed, and of most of the southern half of the watershed of the Lake of the Woods Proper, indicated that high discharge followed soon after heavy precipitation, and that during the winter season and during dry weather, the discharge of these streams fell to a relatively small value. Such fluctuations in discharge as these are to be expected when the character of these watersheds is considered.

It will be observed as a striking fact, shown on Plate 106, that during the fall and winter months, almost all of the inflow into the Lake of the Woods represents outflow from Rainy Lake. During exceptionally dry seasons such as September and October, 1906, October, 1908, July to November, inclusive, 1910, July and August, 1911, September, 1913, and August, 1914, that portion of the watershed of the Lake of the Woods below Rainy Lake did not furnish sufficient runoff to supply even the evaporation from the Lake area. It may be remarked that these dates are taken from the period subsequent to November, 1905, and for which period observed runoff values are available.

The gradual and relatively similar variation in rates of outflow from Rainy Lake in a state of nature, for different years, is well illustrated by the curves of outflow for 1905, 1906, 1907, and 1908. These curves are used as a guide in drawing curves of outflow for the previous years. In addition, meteorological data, such as precipitation, temperature, evaporation and transpiration losses, and other physical data, were brought to bear on the determination of the probable natural outflow from Rainy Lake during the period of years from 1892 to 1905.

The fact that melting snow and rain falling on the Lower Rainy watershed and the watershed of the Lake of the Woods, Proper, quickly finds its way into the Lake of the Woods, is indicated on Plate 106, by the data for the following months: April to June, 1906; April to June, and August to September, 1907; April to June, 1908; May to June, and October to December, 1909; March to May, 1910; April to June 1911; April and May, and September and October, 1912; April to July, 1913; and April to July, and September to October, 1914. It is quite evident that the forests and swamps of the Lower Rainy watershed cannot compare, in their equalizing effect on runoff, with the large lakes of the Upper Rainy watershed.

RESERVOIR CONTROL IN GENERAL

Whenever the natural outflow from lakes is subjected to control by human agency, the natural regimen of outflow from such lakes is at once superseded, and a new regimen of lake levels is established.

The extent to which levels prevailing under a state of control differ from those which, in a state of nature, would have prevailed at the various seasons of the year, and also the effect of the new regimen of levels upon the riparian land, depends largely upon the character and extent of the control which is being exercised over the outflow from the lake. However, any control of outflow, whatsoever, results in higher than natural lake levels at all seasons of the year, unless the discharge capacity of the outlet is increased over what it was in a state of nature.

Control of the outflow from any lake, with a view to its equalization, presupposes the storage of flood water. Such a lake, then, acting as a storage reservoir, will frequently become filled at a time when the rate of inflow is high. The frequency with which this condition will recur will depend upon the extent to which the outflow can be equalized by the available storage, i. e., the filling will recur more frequently with a reservoir of relatively small storage capacity than with one of relatively large capacity. The extent to which flood water can economically be utilized in the equalization of stream flow depends upon the cost of flowage rights, and the cost of impounding and other works required for the utilization of the stored water, as compared with the benefits accruing to the various interests utilizing this water.

In the operation of all storage reservoirs whose capacity is insufficient to completely equalize the outflow over a long period of years,—and in principle this means essentially all of them—a time will come, if the ordinary high level is not to be exceeded, when the discharge of water, even under the most intelligent operation, must be substantially greater than the maximum outflow in a state of nature. The maximum rate of outflow to be expected under a state of control will equal the maximum rate of inflow which may occur at any time while the reservoir is full to its ordinary high level, unless special provision has been made for reserve storage capacity which is not permitted to be utilized except in years of extraordinary floods, and at times when excessive precipitation, such as 5 or 6 inches, falling on the lake and on the adjoining watershed in a few days, will raise the level of the

lake at least an equal amount. If reserve storage capacity has been provided, the high rate of inflow can be absorbed, partly by increased outflow and partly by increased storage on the lake, exactly as in a state of nature.

In the case of lakes in their natural condition, a rising stage and an increasing rate of inflow results both in an increasing rate of outflow and further storage. It follows, then, that in a state of control, when a reservoir is permitted to fill in other years besides the one year of maximum flood, occurring perhaps once in twenty-five or fifty years, the discharge capacity of the reservoir must be very substantially larger than the greatest natural discharge capacity, or else the lake will, sooner or later, rise above its ordinary high level and above its extreme natural high water stage. Without increased outflow capacity, any control of outflow, whatsoever, must inevitably result in raising the lake to a higher level than the highest stage which would have occurred during the given period in a state of nature.

REGULATION OF OUTFLOW FROM RAINY LAKE

Having obtained what we believe to be substantially correct values of runoff from the Upper Rainy watershed from 1892 to 1915, we may now make a study of the extent to which it appears practicable and desirable to regulate the outflow from Rainy Lake in order to aid in regulating the levels and outflow from the Lake of the Woods; and at the same time to ensure the advantageous use of the waters of Rainy Lake itself. The necessity for this special consideration of Rainy Lake will be appreciated when it is realized that the Rainy Lake watershed at Fort Frances and International Falls constitutes 54.2 per cent of the total drainage area of the Lake of the Woods and contributes 62.0 per cent of the total runoff.

Although the inflow into Rainy Lake for a number of years has, to some extent, been controlled by dams located at the outlets of a number of tributary lakes, yet, so far as our present study is concerned, the effect of these dams,—most of which are used in connection with logging operations—has been relatively small. The respective locations of these dams are shown on Plate 126; and such data as it has been possible to obtain relating to the dams, and to their possible influence on the inflow into Rainy Lake, are assembled in Table 87.

In general, the method of operating most of these logging dams consists, first, in storing water during the fall, winter and early spring; and subsequently releasing it soon after the spring break-up,—usually about May 1st—when the sluicing of logs begins. On a number of lakes, the storage capacity compared with the area of the tributary watershed is so small that the effect of the dams on the distribution of the runoff is practically negligible. In the case of some of the other lakes, however, a substantial portion of the winter and spring flow is held back until the period when it is required for the sluicing of logs. The usual effect of the operation of most of the logging dams is to accentuate the irregularities in outflow from those lakes which the dams respectively control.

One of the best means for determining a satisfactory method of regulation of outflow, and regimen of lake levels, is by study of a mass curve of runoff, or inflow. This curve represents, merely, summations of the volumes of runoff or inflow over certain adopted units of time. Such summations are plotted with respect to time, consequently every point on the mass curve of inflow represents the

net quantity of water which has run into the lake from the beginning until the close of the period under consideration. The slope of the curve at any point represents the *rate* of inflow at that time.

Studies are presented on Plates 127 and 128 of two methods of regulating the outflow from Rainy Lake. Each method of regulation has been applied on the assumption of both 100 and 150 billion cubic feet of total available storage capacity.

The mean area of Rainy Lake is 345 square miles, consequently its storage capacity is 9.6 billion cubic feet per foot of depth, or a total of 67.2 billion cubic feet for a fluctuation of 7 feet. Such a range, for example, would be afforded between elevations, say, of 490 and 497, Department of Public Works, Canada, datum. The latter elevation, it may be observed, is that of the crest of the dam at International Falls and Fort Frances.

During the past few years, while the outflow from Rainy Lake has been under control, the fluctuation has actually been greater than 7 feet, so that under present conditions of control, the available storage capacity on Rainy Lake may be considered to be about 70 billion cubic feet. Since the construction of the Kettle Falls dams, a general plan of which is shown on Plate 101, at the outlets of Lake Namakan, in 1914, about 100 square miles of additional lake area has become available for storage. This area embraces Namakan, Kabetogama, Sand Point, Crane, and Little Vermilion Lakes, and their connecting waters. As the storage per foot depth on these lakes is 2.8 billion cubic feet, a total storage capacity of 30 billion cubic feet could be obtained by a draft of a little less than 11 feet. Contemplated power developments on the Vermilion and the Kawishiwi Rivers would provide additional storage capacity.

A storage capacity of 150 billion cubic feet could be obtained by increased storage on Rainy Lake, and the lakes controlled by the Kettle Falls dams, or else by means of the secondary storage available on such lakes as Vermilion, Birch, Manitou, Otukamamoan, White Otter, Lac La Croix, Basswood, and Saganaga.

The storage, therefore, which may be considered available under present conditions, is not less than 100 billion cubic feet. This storage may be expected to be available even though it should become desirable, in the future, to reduce the range of fluctuation in level of Rainy Lake, or of the lakes above Kettle Falls, or both.

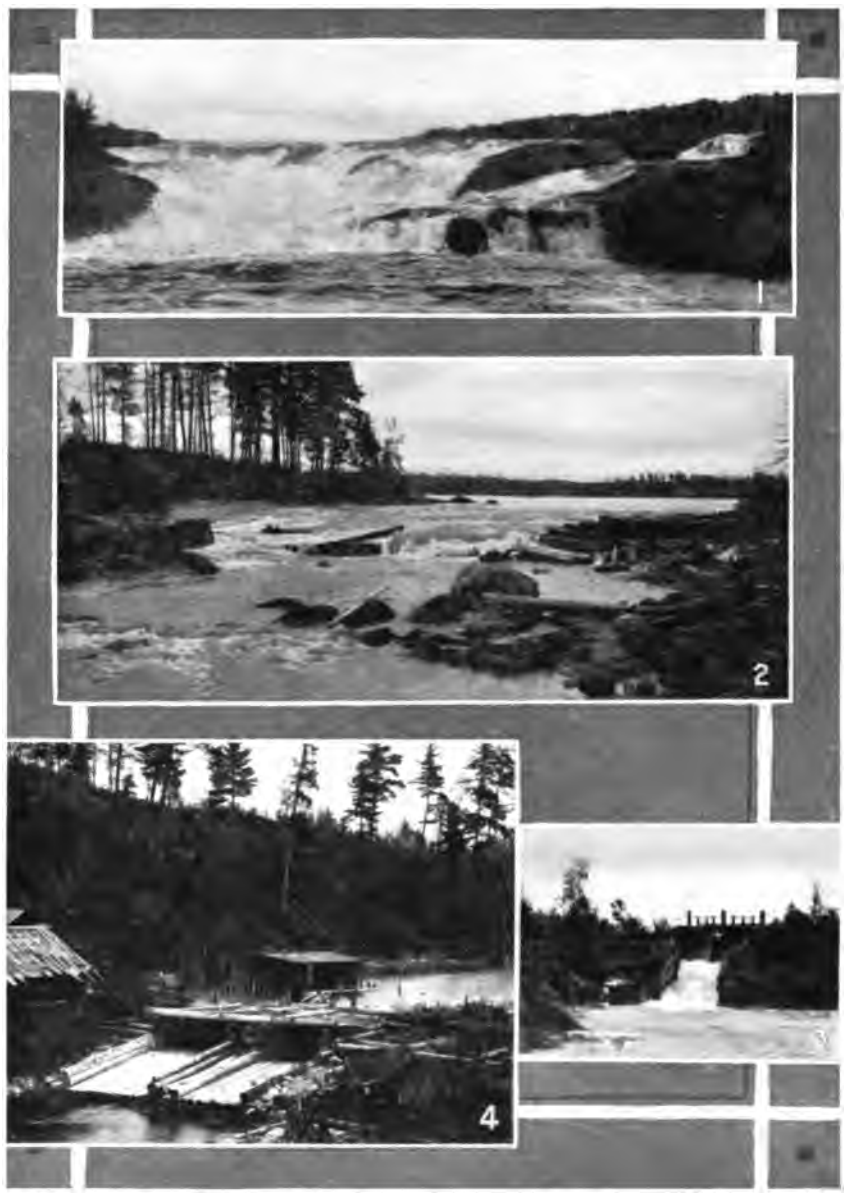
It is well known to those familiar with meteorological studies, that consecutive years of low precipitation and consequently low stream flow, occur in more or less readily distinguishable cycles of twenty-five or more years. In the period of years under consideration, 1892–1914, the extreme low water period extends from July, 1910, to July, 1913, when considering the case of 100 billion cubic feet of total storage capacity; and for the case of 150 billion cubic feet of

PLATE RR

CANADIAN CHANNEL AT KETTLE FALLS—OUTLET OF LAKE NAMAKAN BEFORE CONSTRUCTION OF DAM—1913

INTERNATIONAL CHANNEL AT KETTLE FALLS—OUTLET OF LAKE NAMAKAN BEFORE CONSTRUCTION OF DAM—1913

PLATE SS



1. CURTAIN FALLS AT OUTLET OF CROOKED LAKE
2. FALLS AT OUTLET OF BASSWOOD LAKE
3. DAM AT OUTLET OF BIRCH LAKE ON INTERNATIONAL BOUNDARY
4. DAM AT OUTLET OF KNIFE LAKE

total storage capacity the extreme low water period extends from July, 1910, to at least July, 1915. The greatest depletion, in each case, would have occurred in April, 1912.

The characteristic feature of the first method of regulation, which in the following pages will be termed Method A, is to limit the outflow, whenever the reservoir storage is being drawn upon, to the highest possible rate which, by the judicious use of storage, can be maintained during the extreme low water period, extending over some years. Whenever the reservoirs are full and water is being wasted, a higher rate of discharge may, of course, be economically utilized.

Under Method A, an effort is made to fill the reservoir each spring on the assumption that it cannot be foretold whether the succeeding summer, or indeed the succeeding years, may or may not be the exceptionally dry period over which it is intended to equalize the flow, and to do which would require, at the beginning of the dry period, a full reservoir.

Under the second method of regulation, which will be termed Method B, the aim, in general, is to augment to the greatest possible extent the ordinary recurrent, or yearly low water flow, and to utilize the largest possible portion of the available runoff from the tributary watershed, insuring that this runoff maintains, for much the larger proportion of the total time, a high *uniform* rate of outflow from Rainy Lake. In the present case in particular,—unless danger of total depletion of the available storage is imminent—effort is made to maintain and to utilize, as far as possible, a minimum outflow of 10,000 c. f. s. This rate is approximately the capacity of the present installation at Fort Frances and International Falls, and almost equal to the average flow for the past twenty-two years.

The shaded areas on the graphs, Plates 127 and 128, indicate the amount of water which would have been wasted under the two methods of regulation. It is at once apparent that, under Method A, very much more water would have been wasted than under Method B. On the other hand, 100 billion cubic feet of available storage capacity, under Method A, would have provided a uniform flow of 5835 c. f. s. during the extreme low water period from July, 1910, to July, 1913; whereas under Method B, by which the flow of 10,000 c. f. s. is maintained into the dry period as far as practicable, the same 100 billion cubic feet of storage would have resulted in a low water flow, from July, 1910, to April, 1911, of only about 3500 c. f. s. Generally speaking, it may be said that, under Method B, the natural low water flow extending over a period of exceptionally dry years is not substantially increased; whereas, under Method A, the increase is very considerable,—a fact, indeed, to be expected, inasmuch as this increase in the extreme low water flow is made the governing consideration of regulation in this Method A. In other words, under Method A, a uniform

rate of outflow is maintained over the entire dry period of some years, and this rate is considerably higher than the minimum to which the regulated flow would fall under Method B.

It has been computed from the various regulated rates of discharge under Method B shown on Plate 128, that an increase in available storage capacity of from 100 to 150 billion cubic feet, results in an average increase in utilized discharge, extending over a period of more than twenty-two years, of only 247 c. f. s. This is less than 3 per cent of the average discharge which could have been utilized during this period with 100 billion storage. The *extreme* low water flow for the fall and winter of 1910–1911 would, also, only be increased from 3500 to 4330 c. f. s.

From the standpoint of equalization of flow alone*, it may be stated, that if the Upper Rainy reservoirs are to be operated according to Method B, additional storage capacity over and above the 100 billion cubic feet at present available cannot, economically, be provided. If storage on the upper lakes is feasible at all, it must find its justification, primarily, in the increased advantages resulting from a reduction in the extent of the fluctuation of the level of Rainy Lake itself, coupled with such benefits as may be derived, locally, from the storage of water in the secondary reservoirs. On the other hand, if the Upper Rainy reservoirs are to be regulated according to Method A, an aggregate storage capacity of 150 billion cubic feet would increase the low water flow from 5835 c. f. s. to 6710 c. f. s. or about 15 per cent above what could have been obtained from 100 billion cubic feet of storage.

Now, in order to show the effect of these two methods of regulation on power development at International Falls and Fort Frances, the frequency curves of Plate 131 have been prepared. The computations from which these curves have been made show that on an average, with 100 billion cubic feet of total available storage capacity, 1968 more horse power would have been available if Method of Regulation B had been applied instead of Method A.

In making this power study it has been assumed that the secondary storage above Rainy Lake would first be drawn upon, and that during the spring runoff the draft on Rainy Lake, made during the previous winter, would first be replenished. In this power study the available head was determined by subtracting the mean tail water level for each month from the mean head water level. The tail water level was determined from the rating curve of discharge of Rainy River, Plate 85, by adding .2 foot for average fall between the gauge to which this rating curve is referred and tail water at the power plant. The head water level was determined by subtracting the fall corresponding to the given stage and discharge, as

* See statement of Mr. Meyer in "Final Arguments," Levels of the Lake of the Woods, Washington, D. C., April, 1916, pages 217–223.

determined from the curves of Plate 86, from the Rainy Lake level. In addition, a correction was made for backwater. During the winter months and during the period of heavy spring runoff, from December 1st to June 1st inclusive, a correction of one and one-half feet was made for backwater due to ice on the Rainy River, and to floods occurring on the lower tributaries of Rainy River. Between June 1st and December 1st, an average allowance of one-half foot was made for backwater. With these essential data at hand, the available horse power was then computed on the basis of an over-all efficiency of 75 per cent.

The effect of the various methods of regulating outflow from Rainy Lake on regulation of the levels and outflow from Lake of the Woods will be discussed later. Yet, it may here be commented that, from the viewpoint solely of the advantageous utilization of the waters of Rainy Lake, the more desirable method of regulation is clearly that termed Method B, and which, as before stated, aims to utilize, for power development, the greatest amount of water without making any attempt to substantially increase the *extreme* low water flow which may or may not recur once in twenty-five or more years. The *extreme* low water flow, during such low water period, when it does occur, may only extend over a few months or perhaps a year, and may be expected as an accompaniment of a protracted period of deficient precipitation extending over, say, three, four or five years.

According to the records of the Minnesota & Ontario Power Company, given in Table 90, the maximum monthly average power utilized for paper making and other purposes during 1914 was 27,442 H. P. At a discharge of 10,000 c. f. s. and a lake level of 497, the head water level at the dam would be 496.5, and the tail water level would be practically 465.5 if there were no backwater. Assuming an average of 0.5 foot of backwater during the summer, as before stated, the average tail water level would be 466.0 and the net head 30.5 feet. 10,000 c. f. s., under 30.5 feet head at 75 per cent over-all efficiency, would develop 26,000 H. P. This is the ordinary maximum amount of power which, for the present study, may be assumed available. Method of regulation B, with 100 billion cubic feet of storage on the Upper Rainy reservoirs, would, between 1892 and 1914, have furnished an average of 20,968 H. P. against 19,000 H. P. under Method A. For 25 per cent of the time Method B would have furnished over 25,000 H. P., and, for 50 per cent of the time, over 22,500 H. P. For 25 per cent of the time Method A would have furnished over 22,200 H. P., and, for 50 per cent of the time, over 17,000 H. P. (See Plate 131).

During the protracted dry period, however, the power output under Method B would have fallen to an extreme low value, which is 4000 H. P. less than the least amount of power which would have

been available under Method A. If continuous power is required, therefore, the size of the auxiliary power plant, under Method B, would need to be 4000 H. P. larger than under Method A. This additional capacity, however, might not be required for fifteen or twenty, or more, years to come, and could be installed when the protracted dry spell was at hand. Even if provided immediately, however, this additional installation would represent an annual fixed charge of only about $35,000.

Between 1892 and 1914, Method B would have furnished an average of 1968, or practically 2000, horse power more than Method A. The difference between the cost of operation of water power and steam power plants for such blocks of power as are under consideration, is not less than $25.00 per horse power per year for 24-hour power, in favor of the water power, and hence it may be said that Method B is, annually, worth at least a net amount of $50,000 less $35,000, or $15,000, more to the power interests at Fort Frances and International Falls than Method A.

From the viewpoint of damage to riparian owners, on Rainy Lake, Method B would be more desirable than Method A, because for any given total storage capacity and high water level, the average level of Rainy Lake, under Method B, would have been about two feet lower than under Method A. Moreover, under Method B the high water level would have been reached, during the summer and fall months, in only a little more than half as many years, and would have prevailed about half as many months as under Method A.

Navigation interests on the Rainy River below the Lake, under the present state of the river,—that is, with no dam at Long Sault Rapids—would, under all ordinary conditions, have found deeper water, but during a total of seven months, between May 1st and November 1st, out of the twenty-two years, the stage would have dropped lower under Method B than under Method A. If a dam be built at Long Sault Rapids, then navigation interests also would, unquestionably, be better served by Method B.

Granting, now, that regulation according to Method B would permit of the most advantageous use of the waters of Rainy Lake—and we believe no successful combination of these two methods can be applied—it follows, as previously pointed out, that 100 billion cubic feet is about the maximum total storage capacity which need be provided in order to equalize the outflow from Rainy Lake to the greatest practicable extent.*

The question of where this storage capacity can most advantageously be provided, is one which chiefly affects the interests on the upper watershed. With the completion of the Kettle Falls dams during 1914, a total of 100 billion cubic feet of storage capacity has

* So far as this lake alone is concerned.

already become available. Whether a part of this storage capacity shall be provided on other lakes beside Rainy Lake and the Lakes controlled by the dam at Kettle Falls, is largely a question of the cost of storing water on the several available storage lakes. Storage on Rainy Lake is intimately related to available power at the outlet. Every foot of increase in lake level represents an increase of from 800 to 900 continuous horse power. The cost of additional flowage, bank protection, etc., involved in the securing of further storage on this Lake, would be at least partly offset by the increased power which would thereby become available. If such power as might be developed, under low and greatly fluctuating head, at Kettle Falls is not considered, then storage on the lakes above would become primarily a question of the cost of flowage or other damage, and of impounding works, per unit of additional storage capacity secured.

In order to assist in determining the feasibility of utilizing auxiliary storage on the Upper Rainy watershed, surveys and reconnaissance examinations, as previously remarked, were made on Rainy Lake and on Lakes Namakan, Kabetogama, Sand Point, Crane, and Little Vermilion. The maps resulting from these surveys are presented in the Atlas. Reconnaissance examination was also made of other secondary storage lakes on the watershed.

As has been pointed out, the storage capacity required for the greatest practicable equalization of flow from the viewpoint of the regulation of the levels of the Lake of the Woods is already available. With respect, however, to the relative advantages of variously storing water on the other lakes of the Upper Rainy watershed, it may be said that fuller detailed study will embrace this phase of our subject; but time for such study could not now be obtained because of special efforts put forth to the end that the more essential portions of our report would be available for service at the September Hearings.*

The results which would have been obtained during the years 1892 to 1914, from the two methods of regulation of the Upper Rainy reservoirs, as previously discussed, and with either 100 or 150 billion cubic feet of total available storage capacity, may briefly be summarized as follows:

1. From the standpoint of the power interests at International Falls and Fort Frances, Method of Regulation B would have resulted in an average of 1968 more horse power being available than under Method A.

2. An aggregate storage capacity of 100 billion cubic feet is all that need be provided on the Upper Rainy watershed if these reservoirs are to be regulated according to Method of Regulation B.

* See Supplementary Discussion, page 247.

3. Under Method of Regulation A, with 100 billion cubic feet of available storage capacity on Rainy Lake and the lakes above Kettle Falls, Rainy Lake would have been full more than 85 per cent of the time, whereas under Method of Regulation B it would have been full only about 40 per cent of the time. These facts may be seen by referring to the frequency curves, Plate 131.

4. From the viewpoint of damage to riparian owners on Rainy Lake, Method of Regulation B would have been more advantageous because the average level of the Lake would have been about two feet lower and the high level would have prevailed only half as long.

5. The following rates of outflow would have prevailed:

	Minimum Outflow	Maximum Outflow	Average Utilizable Outflow
UNDER METHOD A			
	c. f. s.	c. f. s.	c. f. s
With 100 billion cu. ft. storage	5635	31241	7614
With 150 billion cu. ft. storage	6710	28387	7883
UNDER METHOD B			
With 100 billion cu. ft. storage	3500	27651	9029
With 150 billion cu. ft. storage	4230	27651	9276

6. Under Method B, throughout all seasons but one in twenty-two years, a greater ordinary flow would have been available between May 1st and October 1st, for navigation on the Rainy River below the International Falls-Fort Frances dam than under Method A. After July 1st, during that one year, the flow would have fallen to about 3500 c. f. s., which is less than is required for satisfactory navigation of the River.

7. For about nine months during the extreme low water period, 4000 less horse power would have been available under Method B than under Method A; that is to say, if continuous power is needed, the capacity of the auxiliary power plant under Method B would require to be 4000 horse power larger than under Method A.

REGULATION OF LEVELS AND OUTFLOW—LAKE OF THE WOODS

We shall next consider the effect which the two methods of regulating the outflow from Rainy Lake, both with 100 and 150 billion cubic feet of total storage capacity, will have upon the regulation of the levels and outflow from the Lake of the Woods.

The regulated outflow from Rainy Lake has been combined with the runoff from the drainage area below Rainy Lake, according to several different schemes, and the results are presented in the mass curves of inflow into the Lake of the Woods, Plates 132 to 135C.

Comparison of these mass curves may best be made in pairs. The first two, Plates 132 and 133, show the results obtained by applying method of regulation A on the Lake of the Woods—the outflow from Rainy Lake being similarly regulated—with both 100 and 150 billion cubic feet of total storage available on the Upper Rainy reservoirs.

Inasmuch as, under this method of regulation, the Lake of the Woods reservoir is considered, under normal conditions, to be filled each spring,—in which event it may be assumed to be full at the beginning of the protracted dry period—a study is first made of the equalization of outflow which could have been effected over the dry period by means of various drafts on available storage on the Lake of the Woods itself. This dry period began June, 1910, and, for total drafts greater than 3 or 4 feet, extended beyond December, 1914, although no one can predict its termination. In view of the fact that the maximum draft on storage, for the higher rates, occurred in the spring of 1914, there is some doubt whether these high rates could really be maintained through the coming years. Assuming, however, that greater depletion would not have occurred in the spring of 1915 or later, then the increase from 100 to 150 billion cubic feet of storage capacity on the Upper Rainy watershed would have resulted in an increase in the low water flow from the Lake of the Woods over the dry period of years, according to the values given in the following table:

METHOD OF REGULATION A ON BOTH UPPER RAINY RESERVOIRS AND LAKE OF THE WOODS

Max. Draft on Lake of Woods in Feet Depth on Lake Area	Regulated Outflow from Lake of the Woods			
	100 Billion Cu. Ft. Total Storage Capacity Upper Rainy	Increase per Foot	150 Billion Cu. Ft. Total Storage Capacity Upper Rainy	Increase per Foot
3	8950	.....	9620	.....
4	9670	720	10330	710
5	10390	720	11050	720
6	10770	380	11400	350
7	11120	350	11740	340

It is at once apparent from an examination of the curves of Plates 132 and 133 and from the preceding table, that for each of the quantities of available storage under Method A, drafts of 3, 4 and 5 feet in depth on the Lake of the Woods result in a much greater increase, per foot of draft, in the regulated outflow than do the higher drafts of 6 and 7 feet. This fact would indicate that the most economical maximum draft on storage on the Lake of the Woods, viewed only from the standpoint of determining the maximum rate of outflow, is 5 feet. Adopting then this value, our study may be continued. We will assume, that at the beginning of each yearly period following the filling of the reservoir, the regulated outflow, in accordance with the principle of Method A, is limited to the rate maintainable by a 5-foot draft on storage extending throughout the extreme low water period which began in 1910. This rate of outflow is 10,390 and 11,050 c. f. s. respectively, for the 100 billion and 150 billion cubic feet of total storage capacity on the Upper Rainy reservoirs.

If, some months after the beginning of the yearly low-water period, it is perceived that, owing to increase of inflow, the reservoir has again become filled so that water is being wasted, then the rate utilized may be increased. It has been concluded that the highest rate which thus could have been economically utilized for power development on the Winnipeg River during the wasting period, under method of regulation A, and with 5 feet draft on the Lake of the Woods, would be 13,000 c. f. s. Higher rates of flow than 13,000 c. f. s. would have been available for such short periods of time that it is questionable whether it would have been advisable to have installed the additional machinery necessary for the utilization of a higher rate.

On Plates 134 and 135, a study is presented setting forth the results which could have been obtained on the Lake of the Woods if

both the Upper Rainy reservoirs and the Lake of the Woods itself had been regulated according to Method B, and with both 100 and 150 billion cubic feet of total storage capacity available on the Upper Rainy watershed. Under these conditions of regulation, it appears that it would have been feasible to utilize up to 16,000 c. f. s. in power developments on the Winnipeg River. It has been assumed that this amount of water would be discharged from the Lake at all times except when, on the basis of evidence furnished by existing storage on the Upper Rainy reservoirs and by the winter and spring precipitation on the watershed, the setting in of a protracted dry period could clearly be foreseen.

By means of 100 billion cubic feet of available storage on the Upper Rainy reservoirs, it would have been possible to have secured a minimum regulated outflow from the Lake of the Woods of 7710 c. f. s. on 5 foot draft, and 9140 c. f. s. on 7 foot draft. With 150 billion cubic feet of available storage it would have been possible to have increased the low water flow to 8570 c. f. s. on 5 foot draft, and to 10,000 c. f. s. on 7 foot draft on the Lake of the Woods.

Frequency curves of outflow, which furnish a means for ready comparisons of the rate of outflow maintainable from the Lake of the Woods under the different methods of regulation, have been prepared and are shown on Plate 137.

The computations entering into the construction of these frequency curves show that:

1. Under Method A, a storage capacity of 150 billion cubic feet on the Upper Rainy reservoirs would have maintained, with a 5 foot draft on Lake of the Woods storage, an average utilizable rate of outflow which is 384 c. f. s., or 3.4 per cent, higher than that maintainable with a correspondingly used storage of 100 billion cubic feet.

2. Under Method B, 150 billion cubic feet storage on the Upper Rainy reservoirs would have maintained, with 5 foot draft on the Lake of the Woods storage, an average utilizable rate of outflow which is 87 c. f. s., or 0.6 per cent, higher than that maintainable with a correspondingly used storage of 100 billion cubic feet.

The quantities expressing the utilizable rates of outflow which could have been maintained over the years 1892 to 1914 are summarized on the following page:

SUMMARY OF UTILIZABLE OUTFLOW FROM LAKE OF THE WOODS

Method of Regulation on both Upper Rainy and Lake of the Woods	Total Storage on Upper Rainy Billion Cu. Ft.	Utilizable Rate of Outflow c. f. s.
A	100	11276
A	150	11660
B	100	14742
B	150	14829

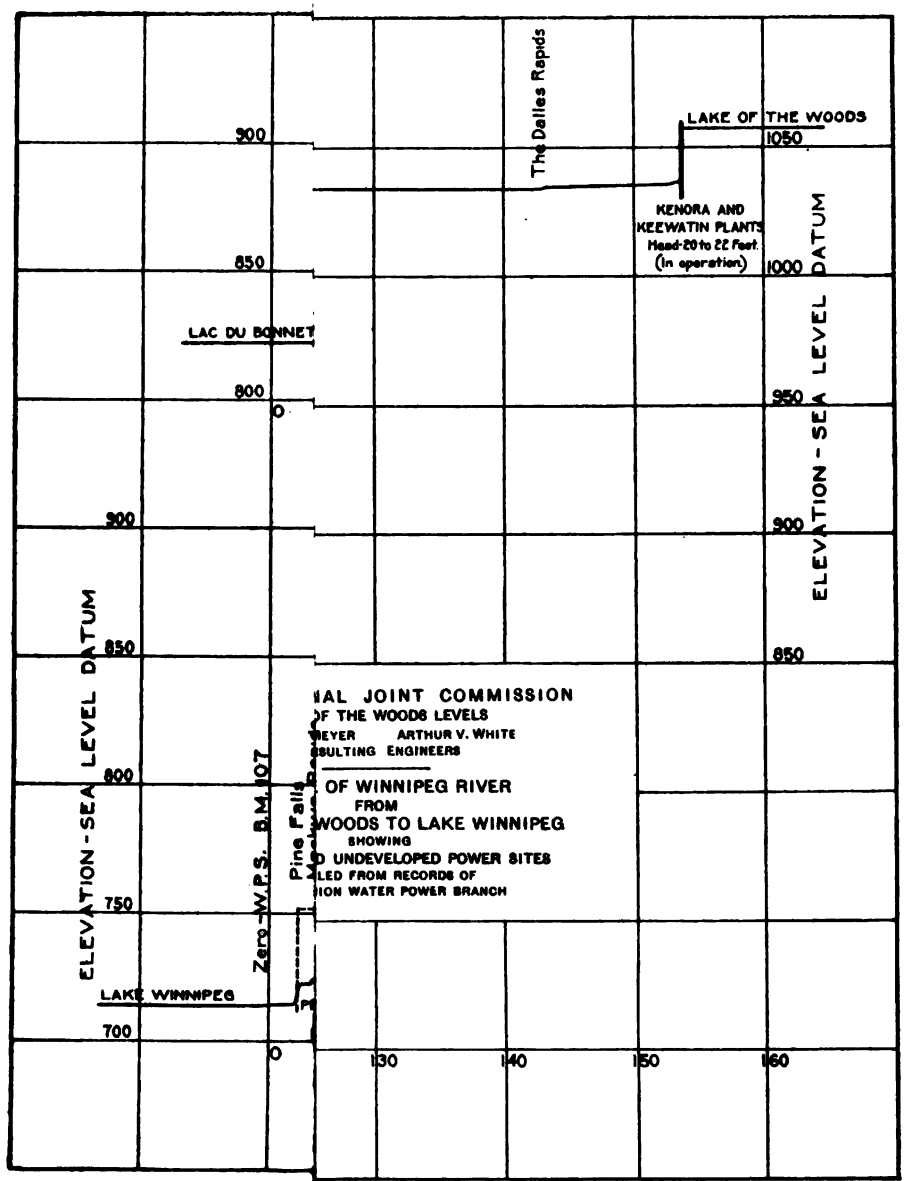
Comparing, now, the two methods of regulation on the Lake of the Woods, in connection with similar regulation on Rainy Lake, it appears that with 100 billion cubic feet of total storage in the Upper Rainy reservoirs, Method B would have permitted the utilization of 3466 c. f. s. or 31 per cent more water than would Method A. With 150 billion cubic feet of storage in the Upper Rainy reservoirs, the increase would have been 3169 c. f. s. or 27 per cent. At the September 1912 Lake of the Woods Hearings, Mr. J. B. Challies, Superintendent Dominion Water Power Branch, stated that "the total fall of the Winnipeg River between the Lake of the Woods and Lake Winnipeg, which can be used for power, is 291 feet."* Translated into horse power produced under 290 feet of available fall, and at 80 per cent efficiency, the above quantities of water represent 91,380 and 83,550 continuous horse power, which, if saleable, at a return of even $10.00 per horse power, would have an *annual* value of $913,800 and $835,500 respectively.

Since the "Advance Sheets" edition of this Report was published, additional studies have been made as shown on Plates 135A to 135C. These studies, and others based on Plates 134 and 135, have been made with a view to determining the maximum extreme low water flow obtainable from the Lake of the Woods, for given conditions of draft and storage, with Rainy Lake regulated by Method B and Lake of the Woods by Method A.

The results appear in the following table:

Regulated Discharge from Rainy Lake c. f. s.	Storage Upper Rainy Billion Cu. Ft.	Method of Regulation Rainy Lake	Uniform Regulated Discharge (Method A) from Lake of the Woods for Various Drafts Below Ordinary Maximum Level					
			3 Ft.	4 Ft.	5 Ft.	6 Ft.	7 Ft.	8 Ft.
			c. f. s.	c. f. s.	c. f. s.	c. f. s.	c. f. s.	c. f. s.
10000	100	B	7760	8510	9260	10010	10760	11510
10000	150	B	8120	8870	9620	10370	11120	11730
9000	100	B	8430	9180	9930	10670	11420	11850
9000	150	B	9170	9920	10670	11410	11850	12190
9000	100 / 50	B / A	9330	10080	10830	11270	11620	11960
8000	100	B	8880	9630	10380	11100	11700	12040
8000	150	B	9780	10530	11250	11780	12120	12460

*See Water Resources Paper No. 3, Department of the Interior, Canada, Dominion Water Power Branch, Winnipeg River Power and Storage Investigations by J. T. Johnston. 2 Vols. (Maps and Plates), Ottawa, 1915.



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OUTFLOW CAPACITY REQUIRED UNDER VARIOUS METHODS OF REGULATION—LAKE OF THE WOODS

As indicated in the discussion of reservoir control in general, Nature's way of absorbing excessive runoff from the drainage area tributary to lakes is both by means of increased discharge, and by storage in the lakes.

In order to take care of excessive runoff under the condition of artificial control of outflow from the Lake of the Woods, either the outflow capacity must be very much increased, or else a certain amount of reserve storage capacity must be provided.

In case of reservoirs whose outflow is regulated according to Method A, either the increased outflow capacity, or the reserve storage capacity, or both, must be very much larger than in the case of reservoirs regulated according to Method B.

To have kept the level of the Lake of the Woods from rising above a prescribed, ordinary, maximum stage, it would, on the basis of the records of the past twenty-two years, with regulation according to Method A on both Rainy Lake and on Lake of the Woods, and with 100 billion cubic feet of total storage capacity on the Upper Rainy watershed, have been necessary, if no provision had been made for reserve storage, to have provided for an outflow capacity of 75,000 c. f. s., or twice what would have been the maximum natural discharge from the Lake during the same period.

With both Rainy Lake and Lake of the Woods regulated according to Method B, it would have been necessary to provide outflow capacity equal to 57,000 c. f. s., if no reserve storage capacity had been provided.

In case both Rainy Lake and Lake of the Woods had been regulated according to Method B, and the outflow capacity of the Lake of the Woods had been increased to 40,000 c. f. s. at the ordinary maximum stage, with correspondingly greater discharge at higher stages, a reserve storage capacity of 0.9 foot would have been required in order to absorb the excess runoff into the Lake in 1896. If regulated according to Method A, more than 2.0 feet of reserve storage capacity would have been required. If regulated according to Method B on Rainy Lake—10,000 c. f. s., and Method A on the Lake of the Woods, a reserve storage capacity of 1.6 feet would have been required. For Method B on Rainy Lake—9,000 and 8,000 c. f. s. respectively, and Method A on the Lake of the Woods, a reserve storage capacity of 1.7 and 2.2 feet, respectively, would have been required.

In case method of regulation B, modified by providing a total discharge capacity of 40,000 c. f. s. at the ordinary maximum level, and also providing for about one foot of reserve storage capacity, were adopted, it would be necessary to discharge 16,000 c. f. s., or over, during all years except the extremely dry ones, because efforts to save water by holding it over because not immediately needed by present installations are likely to result, sooner or later, in a higher lake stage than the prescribed one.

It appears from the curves of Plate 140 that the present outflow capacity of the Western Outlet is relatively small. At a lake stage of 1060 it is possible to discharge only about 25,000 c. f. s., through the Norman Dam, even if wide open. If regulation of the level of the Lake of the Woods is to be secured through control of the outflow through the Western Outlet by manipulation of the Norman Dam, with its present discharging capacity, this site will be economically valueless for any large power development during a portion of every high water year.

In order to discharge more water through the Western Outlet, extensive excavation, particularly at the C. P. R. bridge, and between the bridge and the Lake, would be required, and, with the coöperation of those interested, could no doubt be made.

In order to conserve the water supply, in case power is to be developed in the Western Outlet to a considerable extent, it will be necessary to improve the Norman Dam so as to prevent the present excessive leakage through the rock fill. To permit of ready manipulation of the Dam for regulating purposes sluice gates should be installed or the stop logs and hoist should be kept in good working order under both summer and winter conditions.

A plan of the Norman Dam, giving the dimensions of the sluices and the elevations of the sills of the sluices, is shown on Plate 27.

At a lake stage of 1061.5 the discharge capacity of the Eastern Outlet in a state of nature was 5150 c. f. s. The tail water level at Keewatin, corresponding to a discharge of 40,000 c. f. s., is 1046.5, leaving a head at the Kenora Plant, during flood discharge, of only about 15 feet. Under this head the completed Kenora Plant of 6 generator units and 2 exciters can discharge only about 3500 c. f. s. At the present daily load factor this would represent a continuous discharge of only about 2000 c. f. s., or more than 3000 c. f. s. less than when the Eastern Outlet was in a state of nature. This fact would appear to require recognition when considering the provision of the necessary discharge capacity to permit the regulation of the levels of the Lake.

DESIRABILITY AND PRACTICABILITY OF REGULATING LEVELS AND OUTFLOW—LAKE OF THE WOODS

INTRODUCTORY COMMENTS

The first question of the Official Reference deals with the desirability and practicability of regulating the level of the Lake of the Woods in order to secure the most advantageous use of the waters of the Lake itself, of the waters flowing into and from the Lake, and of the shores and harbors of the Lake.

Numerous and diverse interests, both large and small, are, in varying degrees, dependent upon these waters. Navigation, agriculture, logging and lumbering, fishing, summer outing, water supply and sewage disposal, water power development and manufacturing may here be mentioned as the chief interests which must receive consideration.

Regulation of the level of the Lake of the Woods may, broadly speaking, have in view two objects,—either regulation to secure as nearly uniform lake levels as possible throughout a period of years, or regulation to secure as nearly uniform outflow from the Lake as possible.

Both uniform level and uniform outflow could be obtained only if the inflow into the Lake of the Woods could be completely equalized. Since physical limitations are such that a large portion of this inflow must always remain uncontrolled, both uniform level and uniform outflow cannot be secured.

Any method of regulation which aims to secure either uniform level or uniform outflow, or any combination of the two, will affect the various interests involved in different ways. No single method or combination of methods of regulation will be most advantageous to all of the several interests, consequently "the most advantageous use" of the waters, shores, and harbors of the Lake and of the waters flowing into and from the Lake, must be considered to be that representing the maximum aggregate advantage to all interests involved.

The effect of various methods of regulation on the water power interests at the outlets of the Lake will first be discussed.

WATER POWERS AT OUTLETS

The fall at the outlet of the Lake of the Woods varies both with lake level and with outflow. An increase in lake stage produces a corresponding increase in fall. The available head, however, varies

inversely as the outflow,—that is, the greater the outflow the less the head, because of the rise in tail water level which accompanies increased outflow. The most desirable condition for the water powers at the outlets of the Lake would be to have both a high uniform level and a uniform outflow. It being impossible, as stated before, to obtain both of these results at the same time, the most advantageous conditions, therefore, can only be determined by weighing the advantages and the disadvantages resulting from each given method of regulation.

To equalize the outflow it is necessary to fluctuate the level of the Lake, and the result of any variation in lake level, below the highest level permitted, is to reduce the available power, because it reduces the head water level, and, consequently, the available head.

A study has been made of the power which would have been available at the outlets of the Lake during the period of years from 1892 to 1914:

First, under natural conditions.

Second, with 100 billion cubic feet of available storage capacity on the Upper Rainy reservoirs, and regulation of both the Upper Rainy reservoirs and Lake of the Woods according to Method A.

Third, with 100 billion cubic feet of storage capacity on the Upper Rainy reservoirs and regulation of both the Upper Rainy reservoirs and Lake of the Woods according to Method B.

The results of this study are shown in the frequency curves of Plates 136 to 139, inclusive, from which it appears:

First, that under method of regulation A, the Lake would, on an average, have been full about 30 per cent of the time, and that under method of regulation B it would have been full about 10 per cent of the time, with a consequent greater damage to riparian property under method of regulation A than under Method B.

Second, for every ordinary maximum level which may be established, the available head would, on an average, be about 1.2 feet greater under Method A than under Method B.

Third, if an ordinary maximum level of 1061 had been established, for example, method of regulation B would, on account of the increased utilizable flow and notwithstanding the fact that the average head would have been 1.2 feet less than under Method A, have resulted in an average of 4654 more available horse power than Method A, and 4190 more horse power than in a state of nature.

Fourth, if an ordinary maximum level of 1060 had been established, method of regulation B would have resulted in an average of 4359 more available horse power than Method A, and an average of 2934 more horse power than in a state of nature.

Fifth, if an ordinary maximum level of 1059 had been established, method of regulation B would have resulted in an average of

4064 more available horse power than Method A, and an average of 1678 more horse power than in a state of nature.

It would appear from the computations on which the curves of Plate 138 are based, that if the outflow from the Lake had been regulated according to Method B, and the ordinary high level maintained had been 1057.7, practically the same amount of power would, on an average, have been available at the outlets of the Lake under this method of control as would have been available under natural conditions.

If, now, method of regulation B were modified slightly so that extraordinary rates of inflow into the Lake could be partly absorbed by additional storage capacity on the Lake, then the existing high rates of discharge prevailing for a very small per cent of the time would be considerably reduced and the flood-water head would be increased. Method B thus modified, then, will permit of the more advantageous use of the water flowing from the Lake under regulation, even with an ordinary high level of 1057.7, than under natural conditions. If any higher level than 1057.7 is established as the ordinary maximum level, regulation according to modified Method B will be more advantageous for power developments at the outlets of the Lake—using up to 16,000 c. f. s.—than the natural, unregulated level and outflow, but it would not be as advantageous as the conditions which these interests have enjoyed during the past twenty years, unless the ordinary maximum level is fixed at 1061.5 or above.

Under method of regulation B, every foot increase in the ordinary maximum level,—that is, the high water level which is not to be exceeded except perhaps once in twenty or thirty years—represents an increase of 1256 horse power in the average power available at the outlets. On the other hand, however, every foot increase in lake level results in an almost equal reduction in the available fall at the Long Sault Rapids, and at all other developed or undeveloped water power sites at which the level of the Lake of the Woods determines the elevation of the tail water; that is, the increase in power at the outlets, resulting from an increase in lake stage, would be offset by nearly as great a reduction in the power which could be developed at other sites. So far, then, as the utilization of the waters of the Lake of the Woods for *power development only*, both at the outlets and at the Long Sault Rapids, in particular, is concerned, there would appear to be no advantage in maintaining the Lake of the Woods at a higher level than ordinary natural high water. In case only the present water consumption of existing power developments is taken into consideration, however, each foot increase in lake stage would result in an increase of about 225 continuous horse power, or about 375 horse power at the time of maximum demand.

Apart from international considerations, but viewed from the standpoint of the interests holding water power rights or privileges at the outlets of the Lake of the Woods, and on the Winnipeg River, it may be urged by such interests that they have undertaken developments during periods while the Lake of the Woods has been under control, and that, consequently, they are entitled to at least as advantageous conditions as they have enjoyed under such control as has been exercised in the past in the interests of navigation.

NAVIGATION AND LUMBERING INTERESTS

Navigation on the Lake of the Woods consists, principally, of the towing of logs and the transportation of freight and passengers by steam and gasoline boats. Most of the gasoline boats are of relatively light draft, requiring from two and one-half to four feet of water. Most of the steamboats vary in draft from about four to six feet, a few of the larger boats being reported as drawing from eight to ten feet of water.

The effect of various levels on the navigation and the summer resort interests, in the vicinity of Kenora, is, in large measure, determined by the depths in the various navigation channels and harbors of the Lake, by the available depths of water leading into the boat houses, and by the elevations of the boat house floors and the tops of docks. Information relating to boat houses and docks is summarized in the frequency curves of Plates 141 and 142.

The total value of docks in the vicinity of Kenora and Keewatin in 1914, before the construction of the large Kenora Municipal Dock, amounted to substantially $35,000. The total value of boat houses amounted to $185,000. It appears from the frequency curves of Plate 141 that the tops of all docks in the vicinity of Kenora and Keewatin are at, or above, an elevation of 1061 sea-level datum, and that the boat house floors are all above an elevation of 1059.5,—over 90 per cent of them being above 1061. Only about 50 per cent of both docks and boat house floors, however, are above elevation 1062.0.

The lumbering interests are affected by the levels of the Lake of the Woods, mainly, in so far as the stage of the Lake has a bearing on the facility with which logs can be gotten out of the various bays and inlets, and then towed across the Lake, and hoisted into the mills by means of jack ladders. In low water the towing channels become narrower and more difficult of navigation with log booms, through the protrudence of reefs above the water surface. Low stages, that is, stages below about 1058, would also require additional dredging in harbors and navigation channels in various portions of the Lake. At the January, 1914, Hearings in Washington, Colonel Charles L.

Potter, U. S. A., in charge of the District which includes the United States portion of the Lake of the Woods, testified that the cost of dredging the harbors of Zippel and Warroad was $9,600 per foot increase in depth.

Evidently the most desirable level for the navigation interests, the lumbering interests, and the summer resort interests on the Lake, would appear to be a fairly high, uniform level, irrespective of what the outflow may be.

Navigation interests on the Winnipeg River between Kenora and Minaki are affected by fluctuations in the outflow from the Lake. In view of the fact that at low water there is less fall and hence less current at The Dalles than at high water, moderately low rates of outflow from the Lake of the Woods are more favorable for navigation on that portion of the Winnipeg River than high rates. Very low rates of discharge, however, are unfavorable to navigation of the River immediately below the outlets of the Lake. It follows then, that any regulation of levels and outflow which results in either very low or very high rates of outflow from the Lake is detrimental to the navigation interests on the Winnipeg River below the outlets of the Lake.

RIPARIAN LANDS

If the utilization of the maximum amount of low land adjoining the Lake, and which may be brought under cultivation, be considered, then the most desirable condition for agricultural interests is a low level. These interests are not directly concerned either in the outflow or in the fluctuation in lake level, so long as the highest level to which the Lake is permitted to rise is a low one.

According to results obtained from the instrumental surveys of the southerly shore of the Lake of the Woods, and portions of Shoal Lake and Big and Bigsby Islands, it appears that all of the cultivated land below the 1064 contour (of which there are only about 275.1 acres in the United States and 66.8 acres in Canada) lies above the 1060 contour, and all but 84.6 acres lies above the 1062 contour. Practically all of the land, in the United States, above the 1060 contour has little or no covering of peat vegetation. Below the 1060 contour the peat cover gradually increases, but hardly anywhere, even at the lake shore, does it reach a thickness exceeding 1.0 or 1.5 feet. This is apparent even from a comparison of the contours giving the elevation of the bed of the Lake at the shore-line, with the contours on the adjacent land.

Practically no timber is found, at the present time, below the 1060 contour. Ninety-five per cent of all the land below the 1059 contour consists of open marsh or bog, and the remainder is covered with willows and brush.

Between the 1058 and the 1060 contours there are approximately 16,000 acres of land, or 8000 acres per foot increase in elevation. Above the 1060 contour the area is substantially 12,000 acres per foot, the slopes becoming very slightly steeper again above the 1062 contour.

While the riparian owners on the Lake of the Woods are affected by the levels resulting from various methods of regulation, riparian owners on the Winnipeg River are affected by rates of outflow from the Lake resulting from such regulation.

FISHING INTERESTS

The most desirable level for the fishing interests would appear to be a fairly uniform level, and below the higher stages, particularly in so far as fishing in the Big Traverse is concerned. Some fishing interests have specified levels desirable for the northerly portion of the Lake higher than the levels mentioned as desirable for the southerly portion of the Lake. Uniformity in levels protects spawning grounds and aids in the setting of pond nets. A rather low level results in clearer and purer water, particularly in the Big Traverse, because at high stages the muskegs are broken up by the waves and the vegetable matter is scattered far out into the Lake, making the water dark in color and disagreeable in taste. At the Preliminary Hearings at Warroad, in September, 1912, Mr. Paul Marschalk testified that during the high water of 1905 many fish died, and those which were caught in the Big Traverse became unfit for food within twenty-four hours after being taken from the nets.

INTERESTS USING LAKE FOR DOMESTIC AND SANITARY PURPOSES

So far as the use of the waters of the Lake of the Woods for domestic and sanitary purposes is concerned, the interests primarily affected at the present time appear to be the Greater Winnipeg Water District and the town of Warroad. The Greater Winnipeg Water District is at present constructing an aqueduct from Indian Bay on Shoal Lake, as part of a gravity water supply for the City of Winnipeg and its suburbs. This diversion of water from the Lake of the Woods, for domestic and sanitary purposes, was authorized by your Commission on January 14th, 1914, with the following reservation:

> "That the present permission and order shall not be invoked or relied upon in any manner against the recommendations or report to be made by the Commission on the Reference to it respecting the levels of the Lake of the Woods, and shall in no way interfere with the action of the Commission in that regard."

The bottom of the aqueduct at the intake is at elevation 1050.82, sea-level datum. In order to be able to draw the contemplated 85 million imperial gallons per day, or 158 c. f. s., from Shoal Lake, it

will be necessary for the level of this Lake to be at an elevation of not less than 1058, sea-level datum. Under natural conditions, however, the level of the Lake of the Woods would have dropped very much lower, and the level of Shoal Lake could have dropped to about 1055. The construction of the dams at the outlets has caused higher than natural levels on the Lake of the Woods with the result that the two lakes have since been at substantially the same level. This, to some extent, has been contributed to by the enlargement of the channel at Ash Rapids. Shoal lake might be maintained at a high level by the construction of a dam at the outlet, at Ash Rapids.

The interests of the town of Warroad, in the use of the waters of the Lake of the Woods for domestic and sanitary purposes, would appear to be primarily the use of that body of water for the purposes of sewage disposal.

As the general elevation of the ground upon which the town of Warroad is built is only between 1066 and 1068, sea-level datum, it is evident that the outlet of a gravity discharge system of sewerage could not possibly be placed above even ordinary high water in a state of nature, without raising the house connections of the sewers above the bottom of the cellars and above the frost line. Even under the natural regimen of lake levels, then, it would have been necessary for the town of Warroad to install some form of sewage lift for use during high water. For perhaps half the time, in a state of nature, the sewage might have been by-passed and discharged into Warroad River by gravity.

The present sewerage system at Warroad collects merely the house sewage, storm water being excluded. The sewage flows by gravity into a septic tank from which it is subsequently ejected by means of a siphon operated by a water jet. The discharge pipe is approximately, at elevation 1062.5, sea-level datum.

The increased cost of sewage disposal, to the town of Warroad, directly attributable to increased lake stage, would appear to be about half the total cost of maintenance and operation of the sewage lift.*

NAVIGATION AND POWER DAM AT LONG SAULT RAPIDS

So far as navigation on the Rainy River is concerned, the outflow from Rainy Lake rather than the stage in the Lake of the Woods is the controlling factor in determining the ruling depth on this stream between the Lake of the Woods and the Fort Frances and International Falls dam. A combined power dam and navigation lock at the Long Sault Rapids would permit satisfactory navigation of the River, irrespective of the outflow from Rainy Lake. To be commercially valuable as a power development, however, such a dam would require to be built to an elevation which would result in additional back-

*For detailed reports on relation of lake level to sewerage, drainage and water supply at Warroad, see "Final Public Hearings" 1916, pages 297-309.

water at International Falls and Fort Frances at certain seasons of the year. At present the backwater at this point, resulting from the constricted channel at the Manitou Rapids, averages 1.5 feet for the six months from December 1st to June 1st, and 0.5 foot for the six months from June 1st to December 1st, or an equivalent of practically 2 feet for six months. By prolonging the backwater throughout the open season, an additional head of virtually 2 feet would be gained at the Long Sault Rapids; i. e., more head would be gained at the Long Sault dam than would be lost at the Fort Frances dam.

High discharges from the Big Fork and the Little Fork Rivers result in occasional short periods of extreme backwater at the Fort Frances dam. These extremes are not here given special consideration, other than to point out that it might be feasible to blast out part of the rock ledge forming the Manitou Rapids, so as to reduce, somewhat, the occasional extreme backwater at the Fort Frances dam.

With proper coöperation a 10 to 12 foot power development at the Long Sault Rapids would appear reasonably feasible. Such a development would produce an average of about 9000 horse power.

WATER POWERS ON WINNIPEG RIVER BELOW OUTLETS

The limitations upon the extent to which Nature's method of regulating the outflow from all large lakes can be improved upon by artificial methods of regulation, have already been mentioned in discussing reservoir control in general. Apart from those considerations which involve the preservation of the equity of the various interests, large or small, affected by the levels of the Lake of the Woods and the outflow from that Lake, it would appear that the principal consideration affecting the "development of all the interests involved on both sides of the Boundary," and one which we regard as probably paramount, favoring some intelligent method of regulating the "volume, use and outflow of the waters of the Lake" (of the Woods), and which, so far as practicable, should include the equalization of such outflow, is found in the great amount of water power which can economically be developed on the Winnipeg River below the outlets of the Lake. A regulated flow of 16,000 c. f. s. falling through the 290 odd feet of fall available on that stream, at 80 per cent efficiency, will develop over 420,000 continuous horse power. These water powers, both developed and undeveloped, on the Winnipeg River below the outlets of the Lake, are not directly affected by the level of the Lake of the Woods, so long as they secure adequate range in lake stage to permit of satisfactory equalization of outflow.

As a general rule, it does not pay to utilize water for power development which is available less than 50 per cent of the time;

PLATE TT

BOOMS OF LOGS EXTENDING FOR MILES DOWN THE MINNESOTA SIDE OF RAINY RIVER

MANITOU RAPIDS IN RAINY RIVER

that is, it is cheaper to operate an existing steam or oil power plant,—whose installation is required, in every case where more than the maximum continuously available stream flow is utilized in a water power plant, to supply power demands which must be met the year round, and also in those instances where some insurance against break-downs in the hydro-electric plant or transmission lines must be provided—than it is to pay the fixed charges and operating costs of a water power plant which can be operated less than half the time. The higher the price of coal, and the lower the additional cost of installation for the increased hydro-electric development, the higher will be the rate of discharge which, on a given stream, may be economically utilized. Under conditions prevailing in Canada, particularly on account of the rather high cost of coal delivered in the prairie Provinces, it would probably be feasible to utilize water which is available a somewhat smaller portion of the time. Much would depend upon the conditions surrounding each particular development and the utilization of the power generated.

On the basis of the computed outflow from the Lake of the Woods, which would have prevailed under natural conditions during the past twenty-one years, it may be stated that 16,000 c. f. s. would have been available for nearly 50 per cent of the time. The average amount of water which could have been utilized under natural conditions during this period of time by an installation capable of utilizing 16,000 c. f. s. is 13,980 c. f. s. Under the conditions of control which existed during the same period, about 14,000 c. f. s. would have been available 50 per cent of the time, and the average amount of water which could have been utilized by an installation capable of utilizing 14,000 c. f. s. is 12,174 c. f. s. By regulating the outflow from the Lake of the Woods according to Method B, so as to secure the maximum possible increase in the ordinary seasonal low water flow, by means of a maximum range of 5 feet in the level of the Lake, and with 100 billion cubic feet of total storage on the Upper Rainy reservoirs; in other words, by regulating the outflow so as to make available the greatest possible amount of water, capable of economical utilization in power development, there would have been an average of 14,742 c. f. s. available during the same period of time. While the increase in utilizable flow over that available under natural conditions amounts to only about 5.5 per cent, nevertheless, at $10.00 per horse power per year the average increase in utilizable flow, effected by regulation, would, under the 290 odd feet available fall in the Winnipeg River, represent a possible annual return of about $190,000.

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PREVAILING LEVELS UNDER REGULATION

The levels which would have prevailed on the Lake of the Woods if the outflow had been regulated according to either modified Methods A or B, by providing, for Method A, about 2.5 feet of reserve storage capacity to be used only at times of extraordinary high rates of inflow into the Lake, and for Method B one foot of reserve storage capacity, and on the assumption that a total discharge capacity of 40,000 c. f. s. would have been available at the ordinary maximum level, are shown by means of the frequency curves of Plate 139. Three parallel curves are drawn so as to show the levels which would have prevailed if the ordinary maximum level had been 1059, 1060, or 1061, respectively. For purposes of comparison the curve of natural levels covering approximately the same period of time has also been added.

Regulation according to modified Method B, while necessitating considerable fluctuation in lake level, nevertheless would result in a smaller range, both of yearly and of extreme fluctuation in level, than prevailed under natural conditions.

In case the meteorological conditions which resulted in a natural extreme high water level of 1062.5 should recur, under the condition of control by means of modified Method B, the Lake would rise about two feet above the ordinary maximum level.

Since the "Advance Sheets" edition of this chapter was published, curves similar in character to those on Plate 139, showing the summer levels, for the months of June, July, August and September, have been constructed and are shown on Plate 139A. The upper curves show the summer levels with Method B,—10,000 c. f. s., 100 billion cubic feet storage, applied to the Upper Rainy, and modified Method B to the Lake of the Woods. The lower curves show the summer levels with Method B,—9000 c. f. s., 100 billion cubic feet storage,—applied to the Upper Rainy, and modified Method A,—10,000 c. f. s.,—to the Lake of the Woods.

FROM WHAT BASIS SHALL ADVANTAGE BE MEASURED

In order to determine what practical method of regulation will result in "the most advantageous use of the waters of the Lake of the Woods and of the waters flowing into and from that Lake," and "of the shores and harbors of the Lake," it is necessary, first of all, to determine from what basis advantage shall be measured. Without presuming to establish this basis, we desire to indicate that the regimen of lake levels and outflow which prevailed in a state of nature, at least from the viewpoint of certain riparian owners who, for years, have been protesting against the maintenance of higher than natural lake stages, would appear to afford an appropriate basis from

which to measure the effects of levels which would prevail under various methods of regulation.

In this connection, however, the paramount right of the Federal Government of the United States to hold the level of the Lake at "ordinary high water mark" for the improvement of navigation, must be taken into consideration when ascertaining the net effect of certain regulated levels on the riparian owner. Near the close of our discussion of "Prevailing Levels on Lake of the Woods in a State of Nature," we indicated that a stage of 1059 appears to be fairly representative of ordinary high water stages under natural conditions. The curves on the lower half of Plate 139 show that in case the outflow from the Lake of the Woods were regulated with a view to securing the maximum increase in the ordinary seasonal low water flow, without attempting to store water which can be used only once in twenty or thirty years, and with similar regulation on Rainy Lake; and further, if an ordinary maximum level of 1059 were established and if, whenever that level were reached, the controlling works at the outlets would be opened so as to discharge at least 40,000 c. f. s. if necessary, then the regimen of lake levels resulting from this modified Method B would not be disadvantageous to the riparian owner, when compared with the levels which prevailed in a state of nature. The average level would be a little higher, but the extreme high level would actually be lower than in a state of nature, and the ordinary high level would not be substantially changed.

If, under the same method of regulation, an ordinary maximum level of 1060 were established, the *ordinary* high level would be raised about one foot, but the *extreme* high level reached perhaps once in twenty or thirty years under natural conditions, would not be exceeded. Similarly, if an ordinary maximum level of 1061 were established, the *ordinary* high level would be raised about two feet and the *extreme* high level, occurring perhaps once in twenty-five years, would be raised a little less than one foot above the highest level which would have been reached, under natural conditions, during the period between 1893 and 1913. In other words, with an ordinary high level of 1061, the land between the 1059 and the 1061 contours would ordinarily be submerged for a part of most seasons, and most of the land between the 1061 and the 1062 contours would be submerged for a few weeks perhaps once in twenty years, in addition to being frequently subjected to overflow for a few hours during storms.

If an ordinary maximum level, higher than 1061, were established correspondingly higher lands would be similarly affected.

MISCELLANEOUS ELEVATIONS BEARING ON QUESTION OF DESIRABLE LEVELS FOR LAKE OF THE WOODS

Description	Elevation Sea-level Datum
AT OR NEAR WARROAD	
Cellar floor:	
Warroad Mercantile Company's store	1063.1
Security State Bank	1061.5
State Bank Block	1063.0
C. A. Moody's house	1063.1
Mitchell's house	1062.6
House (Owner unknown)	1061.7
House (Owner unknown)	1062.6
A. M. Landby's house, Sec. 1, T. 162 N., R. 36 W.	1061.8
Discharge pipe of sewage ejector	1062.6
Bottom of inner channel and harbor	1050.0 to 1051.0
Stage giving 7 ft. depth in inner channel and harbor	1057.0 to 1058.0
Bottom of outer channel	1048.0 to 1049.0
Stage giving 7 ft. depth in outer channel	1055.0 to 1056.0
Approximate high-water level above which harbors at Warroad and Zippel would, according to District Officer, require additional break-water protection	1061.0
Approximate general elevation of ground upon which main business district of Warroad has been built	1057.0 to 1057.5
ON SHOAL LAKE	
Floor of intake of Greater Winnipeg Water District aqueduct	1050.82
Lowest lake level at which 85 Million Gallons Daily can be drawn through aqueduct	1058.19
Elevation Greater Winnipeg Water District Bench Mark No. 75	1066.70
AT KENORA	
Kenora Power Plant:	
Floor of generating room	1047.2
Top of head gate piers	1064.6
Top of intake sills—	
3 units	1047.2
4 units	1048.2
Bottom of draft tubes	1036.1
Center of shaft of 40 inch turbines	1051.5
Zero of datum of construction levels	1052.63
James C. Kennedy's high water mark on Tunnel Island	1052.58
Rat Portage Lumber Company's Saw Mill:	
Ground surface at N.W. corner of mill	1061.4
Ground surface of S.W. corner of mill	1062.2
Floor of mill	1064.8
Lake bottom at foot of jack ladder (soft mud)	1056.1
Short's Tie Mill:	
Ground surface on lakeward side of mill	1064.2
Floor of mill	1064.9
Lake bottom at foot of jack ladder (rock)	1042.2
AT NORMAN	
Norman Dam:	
Zero of James C. Kennedy or Keewatin Power Company's datum	960.00
Top of piers of Norman Dam	1064.0 to 1064.3
Sill of eight 21-foot sluices of Norman Dam	1041.9 to 1042.0
Sill of twelve 15.5-foot sluices of Norman Dam	1039.8 to 1040.3
Kendall's Tie Mill:	
Ground surface on lakeward side of mill	1064.0 to 1064.6
Floor of mill	1070.6
Lake bottom at foot of jack ladder (soft clay)	1057.8
Lake bottom 6 feet out from foot of ladder	1056.1
Rat Portage Lumber Company's Tie Mill:	
Ground surface on lakeward side of mill	1067.0 to 1069.0
Floor of mill	1070.4
Lake bottom at foot of jack ladder (soft mud)	1057.8
AT KEEWATIN	
Keewatin Lumber Company's Saw and Planing Mills:	
Ground surface at corner of mill (toe of slope)	1065.2
Lake bottom at foot of jack ladder (dredged in 1911)	1056.1

MISCELLANEOUS ELEVATIONS BEARING ON QUESTION OF DESIRABLE LEVELS FOR LAKE OF THE WOODS—Continued

Description	Elevation Sea-level Datum
AT KEEWATIN—continued	
Keewatin Lumber Company's Tie Mill:	
Ground surface on lakeward side of mill	1063.8 to 1066.0
Lake bottom at foot of jack ladder (soft mud)	1055.2
Lake bottom to west from foot of jack ladder	1055.8
Lake bottom to east from foot of jack ladder	1055.6
Lake bottom 40 feet outward from foot of jack ladder	1056.0
Lake of the Woods Milling Company:	
Mill "C"—	
Top of head gate piers	1064.6
Top of sill of intake	1049.3
Sill of one 20-foot flume	1060.3
Sill of one 20-foot flume	1049.3
Mill "A"—	
Top of piers and stop logs at power house	1062.5
Top of head gate piers	1067.5
Sill of intake to generator turbines	1043.3
Sill of intake to mill turbines	1044.3
Bottom of head race (rock)	1050.0
Stave Mill—	
Ground surface on lakeward corner of mill	1063.1
Floor of mill	1066.3
Lake bottom at foot of jack ladder	1056.0
Lake bottom 30 feet out from foot of jack ladder	1053.2

SUPPLEMENTARY DISCUSSION

INTRODUCTORY REMARKS

In May, 1916, just after the final copy of this Report was ready for the printer, it became evident that unusual flood conditions would prevail on the watershed of the Lake of the Woods. After a conference with the Committee of the International Joint Commission having charge of the Lake of the Woods investigation, it was decided to delay publication of this Report so that cognizance might be taken of any data or special circumstances which might possibly be disclosed as a result of extreme flood conditions.

THE 1916 FLOOD

The heavy snowfall during the winter of 1915–16 was the subject of frequent comment on the part of residents on the Lake of the Woods watershed. Nevertheless, neither the true magnitude of the winter precipitation nor its significance were, apparently, fully appreciated by those in control of the various dams on the watershed, until the flood waters poured down into the reservoirs in uncontrollable volume. No central supervising body, in possession of the complete meteorological and hydrological data essential to safe regulation of these waters, was in existence. Looking back upon the situation now it is readily possible to evaluate the flood producing factors.

On April 11, 1916, the Namakan Lake system of reservoirs was empty. These lakes were lower than they would have been under natural conditions because the outlets of this system of lakes, at Kettle Falls, had been enlarged during the construction of the controlling dams. Rainy Lake had been drawn down 2.3 feet since January 1.

The available reservoir capacity on April 11 on Namakan and Rainy Lakes combined, was 51 billion cubic feet. Inasmuch as the power plant and the mills at the outlet of Rainy Lake would be using water at a rate of about 9,000 to 10,000 c. f. s. the available storage capacity was sufficient to absorb the entire average runoff during April, May, and June of the past twenty-three years. It was also sufficient to absorb nearly twice the average runoff during April, May, and June of the previous seven years during which the plant was in operation.

The Lake of the Woods, on April 11, 1916, was at elevation 1060.2 sea-level datum. At the same time in 1915 it was at elevation 1060.7; in 1914 at 1059.9; in 1913 at 1060.6; in 1910 at 1061.3; in

1908 at 1060.9; and in 1906 at 1060.7. In other words, the Lake of the Woods was not above the normal spring level under the system of control which has been in force during the last ten years.

Although the level of the large storage reservoirs on the Lake of the Woods watershed was not above normal for the spring of the year, the winter precipitation over the watershed, on the other hand, which was to furnish the principal portion of the spring runoff, was very abnormal. The following table gives the average winter precipitation on the watershed subdivisions during the present and during previous high-water years.

WINTER AND SPRING PRECIPITATION INCHES DEPTH ON WATERSHED AREA

Date	Upper Rainy Watershed		Lower Rainy Watershed		Lake of the Woods (Proper) Watershed		Total Lake of the Woods Watershed	
	Nov.-Apr. incl.	Nov.-June incl.	Nov.-Apr. incl.	Nov.-June incl.	Nov.-Apr. incl.	Nov.-June incl.	Nov.-Apr. incl.	Nov.-June incl.
1877-78	10.6	17.2	11.1	18.1	10.9	17.9	10.8	17.5
1879-80	10.0	19.5	9.3	20.9	8.0	17.6	9.4	19.4
1895-96	8.4	16.8	8.9	18.5	8.8	18.0	8.5	17.4
1896-97	7.7	* 12.2	9.4	† 14.5	7.7	‡ 11.7	8.2	§ 12.7
1915-16	12.5	19.4	10.0	16.6	8.3	13.9	10.9	17.6
1915-16 ¶	10.3	17.2	8.0	14.6	6.7	12.3	8.9	15.6

* 19.2 including July.
† 22.1 including July.
‡ 18.2 including July.
§ 19.7 including July.
¶ Deducting precipitation which occurred as rain Nov. 1 to 10.

It appears from this table that the precipitation over the upper Rainy watershed between November 1, 1915, and May 1, 1916, was 18% greater than in any one of the 44 previous years for which we have records, and 25% greater than in 1880, when the precipitation from November 1 to June 30 was a maximum.

Ordinarily, substantially all of the precipitation over the Lake of the Woods watershed between November 1 and April 1 occurs as snow. Nearly all of the November, 1915, precipitation, however, fell as rain during the first ten days of the month and kept up the lake levels during the succeeding winter as shown by the records. The spring break-up was, on the whole, more gradual than usual, resulting in higher evaporation losses from the melting snow and a more gradual runoff of snow-water. Were it not for these ameliorating conditions the lakes would have reached a higher stage than they did,—a stage which, nevertheless, was the highest reached within the period of record. Namakan Lake rose to 511.2, Public Works datum, in May; Rainy Lake rose to 500.9, Public Works datum, in June, and the Lake of the Woods rose to 1064.0, sea-level datum, in July.

It may here be remarked, that if the outlets had been as in a state of nature, in 1916, Namakan Lake, according to our computations, would have risen to about 507.5 early in June; Rainy Lake to

499.6 near the end of June, and Lake of the Woods would have risen to 1060.6 near the end of July.

In this connection, it is interesting to note that Lac La Croix, one of the larger uncontrolled boundary lakes above the Namakan Lake system, reached a stage in May which was 1.3 feet above the principal water-mark on this lake and a little over two feet below the extreme high-water mark. The stage to which this lake rose is relatively the same as the natural stages we have computed for the three large storage lakes, and tends to support the computations. The reason that the levels to which these lakes would have risen under natural conditions in 1916 did not surpass in stage even the most extreme high-water mark shown by the lichen on the rocky shores of the lakes, notwithstanding the fact that the winter precipitation was the highest recorded, is found in the character and distribution of this precipitation and the temperatures which prevailed during the spring, coupled with the fact that the May and June precipitation was much less than during the year 1880 when the extreme high-water marks on this system of lakes as visable prior to 1916 were probably reached, if not indeed formed.

BEARING OF 1916 FLOOD CONDITIONS ON FUTURE REGULATION

Rather more important than the actual levels which prevailed on the three principal storage reservoirs of the Lake of the Woods watershed, or those which would have prevailed if these storage lakes had been in their natural condition, are the probable levels which would have resulted if certain systems of regulation had been in force.

In making a study of such probable levels, it is necessary to assume certain definite methods of regulation. Such methods of regulation, which are here necessarily assumed to be conventional and rigidly applied, may usually be considerably improved upon through the exercise of good judgment and foresight in the actual manipulation of the regulating works.

The two main factors involved in future regulation of these lakes are storage capacity at the beginning of the period of flood flow from the tributary watersheds and the capacity of the respective outlets of the storage reservoirs for the discharge of flood waters. Reliance cannot be placed upon the possibility that, under future methods of regulation permitting the advantageous use of these waters, a larger amount of storage capacity will be available on Rainy and Namakan Lakes in the spring of wet years than was available on April 11, 1916. The discharge capacity of the regulating dams at the outlets of these two reservoirs is ample,* although better gate operating machinery should be installed at both dams.

* Canada's navigation channel is at present used as a sluiceway by the power company. If the six Canadian canal sluices were closed, the total discharge capacity of the International Falls-Fort Frances dam and power plants, between lake stages of 497 and 499.5, would, under present conditions at Pithers Rapids, be reduced by about 8000 c. f. s.

The only way that a repetition of the 1916 flood conditions on the Upper Rainy watershed could be prevented in the future is by having in force by the beginning of the spring break-up, improved methods of regulating the outflow from Rainy Lake, based upon full knowledge of the governing meteorological and hydrological phenomena. Prompt action about April 1, is essential to a complete control of the flood water on this Lake.

During extreme spring floods, the Little Fork and the Big Fork Rivers produce excessive backwater at the International Falls-Fort Frances dam. On April 20, 1916, this backwater amounted to 9 feet. In order to permit of the advantageous utilization of the waters flowing from Rainy Lake for power purposes at International Falls and Fort Frances, it is impracticable to require that a specified amount of water shall be discharged through the regulating works at all times after a certain stage in the lake has been reached because of the excessive backwater which suddenly results whenever the Little Fork and the Big Fork Rivers reach flood stage. One reasonable requirement, for example, would appear to be that in a year of excessive winter precipitation the discharge from Rainy Lake be increased on April 1 to an amount which, in the event of a sudden increment of 7 or 8 feet of backwater, would not raise the tailwater level above a stage permitting of reasonably satisfactory operation of the mills and the power plant at International Falls and Fort Frances. The highest tailwater stage reached in 1916 was 476.5, Public Works Datum, corresponding to a discharge, without backwater, of 38,100 c. f. s. A stage of 477 Public Works Datum, corresponding to a discharge of 39,700 c. f. s. may be taken as about the highest practicable tailwater stage. If, on April 1, 1916, the discharge from Rainy Lake had been increased to 16,730 c. f. s. corresponding to a tailwater level of 468.5, and had been held at this elevation anticipating the arrival of backwater from the Little Fork River, which actually began to manifest itself about April 12, and then after the Little Fork River had crested, the discharge had been increased so as to raise the tailwater level to 476.5 or as near to this as the discharge capacity of the dam permitted at the given lake stage, and had been held at that elevation until Rainy Lake had crested, it would have been possible to have prevented the level of Rainy Lake from rising above elevation 497.2, which is more than 2 feet less than the stage to which this lake would have risen under natural conditions.

If, on the other hand, under the actual conditions of discharge, Rainy Lake had been permitted to fill to 497 before the wasting of water commenced and the discharge had then been increased so as to raise the tailwater level as near as possible to 476.5, and had been maintained at this value until Rainy Lake had crested, a maxi-

mum elevation of 498.2 would have been reached. If the ordinary maximum level on Rainy Lake were increased from 497 to 499.5 Public Works Datum, the discharge capacity of the outlet of Rainy Lake in time of flood would be considerably increased. If, under those conditions, the discharge were increased until a tailwater level of 477 were reached a flood inflow equal to that of 1916 could be absorbed through the use of .7 foot instead of 1.2 foot excess storage, assuming a full reservoir on May 1. If, however, regulation had been taken in hand April 1, it would have been possible to prevent Rainy Lake from rising above the 499.5 level without even utilizing the full discharge capacity.

It is imperative, however, that proper precautions should be taken to prevent the formation of log jams at the Pithers Rapids bridge and the escape of logs from the storage booms on both sides of Rainy River between the Lake and the dam in time of flood.

It may here be noted that the 1916 flood inflow into Rainy Lake was equal to the inflow which, with the outlet as in a state of nature would have produced a stage in Rainy Lake equal to the natural extreme high-water marks as shown by the lichen on the rocky shores.

If the outflow from Rainy Lake were limited to that prevailing at similar stages in a state of nature, any regulation of Rainy Lake, to an ordinary maximum level of 497.0 which would have permitted the reasonably advantageous use of the waters flowing from that lake for power and milling purposes at International Falls and Fort Frances during 1916, would have resulted in a lake stage of 500.7. In order to permit such advantageous utilization of the waters of Rainy Lake, and, at the same time, prevent the lake from reaching excessive flood stages, it is necessary to utilize a larger outflow capacity than existed in a state of nature, and to exercise foresight in the control of the outflow at the time of the spring break-up. The effect of higher than natural rates of outflow from Rainy Lake is not appreciable below the mouth of the Little Fork River. In the lower reaches of Rainy River the stage is determined by the level of the Lake of the Woods and flood discharges from the lower tributaries combined with moderate discharges from Rainy Lake. By increasing the outflow capacity, a higher ordinary stage is possible for any given extreme stage.

If it were not for navigation on the Rainy River, backwater conditions at Fort Frances and International Falls could be considerably alleviated by an enlargement of the channel at the Manitou Rapids where at present there is a rapid increase in fall during high-water stages.

The total amount of water which ran off from the watershed tributary to the Lake of the Woods during high-water years, for which we have records, is shown in the table following.

INFLOW INTO LAKE OF THE WOODS

INCHES DEPTH ON WATERSHED OF 26,750 SQUARE MILES

Month.	1896		1897		1916
April	1.49		2.02		1.82
May	2.57		1.69	*1.67	2.35
June	2.30	*2.23	1.76	*1.70	2.12
July	1.41	*1.33	2.03	*1.94	1.52
Total	7.77	7.61	7.50	7.33	7.81

* Inflow revised in accordance with 1916 high-water discharge measurements which at a tailwater level of 1047.0 show a decrease from the value given in Table 92, of 3500 c.f.s. or 8%, the difference growing less for lower stages and becoming zero at 1042.0.

It will be noted from this table that the quantity of water which reached Lake of the Woods in 1916 was slightly greater than the greatest amount which reached it in any previous year since the beginning of records in 1892.

The inflow, however, was still materially less than flood inflows which occurred previous to 1892, as shown by the fact that the 1916 inflow would, under natural conditions, have produced a stage of only about 1061 as against an extreme natural high-water stage of 1062.5, evidenced by the water marks on the rocky shores.

The flood stage which will be reached on Lake of the Woods under regulation in a season like 1916 will be dependent very largely upon the stage which will prevail on this lake at the time of the spring break-up. The greater the rate of controlled, utilized outflow, the less, on an average, will be the reserve storage capacity required to absorb excessive floods, although the extreme requirement may not be altered unless foresight is exercised in wasting water before the spring break-up. All regulated rates of outflow greater than substantially 11,000 c.f.s. which might have been maintained over the previous dry period, would have reduced the excess storage required if no water had been wasted in advance. No excess storage would have been required in 1916 if the ordinary rate of outflow had been 12,000 c.f.s. This rate could have been secured with 100 billion cubic feet of storage on the Upper Rainy watershed, a regulated outflow of 8,000 c.f.s. from Rainy Lake, and 7.87 feet draft on Lake of the Woods; or with 150 billion cubic feet of storage on the Upper Rainy watershed, a regulated outflow of 8,000 c.f.s. from Rainy Lake and 6.66 draft on Lake of the Woods. The results of these and other combinations of regulation are shown on Plates 135A, B and C. The regulated outflow from Lake of the Woods does not affect the reserve storage capacity required during a series of wet years, however, as the reservoir is full at the beginning of the period of flood runoff, unless water is purposely wasted, as it should be, to provide for the spring flood.

The present capacity of the channel leading to the Norman Dam is entirely inadequate for controlling such volumes of flood water as reached the Lake during 1916 and other high-water years. If the discharge capacity were increased so that when the reservoir was full, a total of 40,000 c. f. s. could be discharged from the lake through all outlets, and if, in time of flood, the controlling works were kept open so that as the Lake rose above its ordinary maximum level the outflow would be increased, the level of the Lake of the Woods could, during 1896 and 1916, without the exercise of foresight, have been controlled within the limits shown in the following table:

Regulated Discharge from Upper Rainy Reservoirs, 100 billion cu. ft. storage	Required Flood Reserve On Lake of the Woods	
	1896	1916
Natural	1.8	1.15
7,680 c. f. s.	2.2	2.34
8,000	2.2	2.01
9,000	1.7	1.26
10,000	1.6	.88

A change in the outflow capacity of Lake of the Woods under various methods of regulation on the Upper Rainy watershed, would have influenced the excess storage or flood reserve required in 1916 as follows:

LAKE OF THE WOODS

	Excess Storage or flood reserve in feet required in 1916 for given rates of regulated outflow and storage on Upper Rainy reservoirs.							
	10000 c. f. s. 100 billion.	10000 c. f. s. 150 billion.	9000 c. f. s. 100 billion.	9000 c. f. s. 150 billion.	8000 c. f. s. 100 billion.	8000 c. f. s. 150 billion.	7680 c. f. s. 100 billion.	Natural Inflow.
Ordinary Maximum Outflow Capacity Lake of the Woods (increase 4000 c. f. s. per ft. increase in stage):								
40,000 c. f. s.	0.88	0.85	1.26	0.78	2.01	1.07	2.34	1.15
45,000	0.58	0.58	0.69	0.54	1.48	0.52	1.82	0.72
50,000	0.38	0.38	0.34	0.34	0.95	0.30	1.32	0.35
Ordinary Maximum Outflow Capacity Lake of the Woods (no increase with increase in stage):								
40,000 c. f. s.	1.30	0.94	1.76	0.88	2.69	1.53	3.17	1.65
48,000	0.48	0.48	0.44	0.44	1.41	0.40	1.88	0.61
48,000 *	0.84	0.56	.....	.....	1.69	1.69	.....	1.19

* Maximum flood reserve required during any season of past 24 years.

With a continuous outflow of 48,000 c. f. s. during the flood period and an inflow equal to that which produced the natural extreme high-water marks of about 1062.5, excess storage equal to 3.5 feet would have been required. With a continuous outflow of 40,000 c. f. s. under the same conditions excess storage of 5.0 feet would have been required. This inflow would be comparable with the 1916

inflow into Rainy Lake and emphasizes the necessity of securing the largest practicable outflow capacity and of exercising foresight by providing storage capacity for flood water. An increase of 10,000 c. f. s. in outflow capacity, for example, would reduce the flood reserve by practically 1.0 foot. By providing for some storage capacity even though water must be wasted in the early spring, so that by the time of the beginning of the spring break-up a certain amount of storage capacity would be available as a precaution against floods, the excess storage might be reduced by approximately, although not quite, a corresponding amount.

In so far as human foresight is concerned, regulation of the outflow from the Lake of the Woods with a view to preventing abnormal stages in that lake, can be much more easily accomplished than similar regulation on Rainy Lake. The condition of the Rainy Lake and the Namakan Lake reservoirs, together with the precipitation on the tributary watershed, will always be a valuable indication of the amount of water to be expected on the Lake of the Woods, so that water may be wasted in the spring after an ample supply for possible succeeding dry years is assured, in order to provide some storage capacity for spring flood water and prevent an undue rise in lake level or excessive rates of discharge.

If, however, no judgment or foresight is exercised in providing storage for extreme flood inflows and if the waste gates controlling the outflow from Lake of the Woods and Rainy Lake were not opened by those in immediate charge until ten days after the beginning of the break-up, Rainy Lake would rise nearly 1 foot and Lake of the Woods would rise about 1.4 foot. In the next ten days both Lakes would rise about 1.4 foot. The reason that Rainy Lake, in spite of its relatively smaller area, does not rise more rapidly than Lake of the Woods is due to the fact that the crest of the flood inflow into Lake of the Woods is reached suddenly in April, almost immediately after the beginning of the spring break-up, whereas the flood inflow into Rainy Lake increases very gradually, reaching its maximum about a month later.

DESIRABLE LEVELS AND METHODS OF REGULATION

At the Public Hearings, navigation interests in Canada indicated 1060.5 to 1061 as a desirable ordinary maximum level, and 1056 as the lowest desirable level during the navigation season. Interests in the United States have indicated that stages above 1060.8 would require some strengthening of existing structures at Warroad and Zippel, and that lower stages would permit of satisfactory navigation in the southern portion of the lake. At the Hearings on the question of the diversion of water from Shoal Lake by the Greater Winnipeg Water District, the United States Engineer Officer in

charge of navigation improvements on the Lake of the Woods indicated that the cost of dredging deeper channels in Warroad and Zippel Harbors was about $9,600 per foot of increased depth. Summer resort interests on the northern portion of the Lake of the Woods have indicated a level of 1060.6 as the most desirable level from their viewpoint. Lumbering and milling interests at the outlets have indicated that stages below 1057 result in increased towing and mill pond costs. The water powers at the outlets have indicated that at stages below 1057 they have difficulty in getting water to their turbines. The principal requirement of the fishing interests is a fairly uniform and not too high a level. The agricultural interests, of course, are best served by a low level.

Now, in order to secure the most advantageous use of the waters of the Lake of the Woods for these various purposes, it is impossible to establish a level or range of levels which will be equally advantageous to all interests involved. The most advantageous use, as previously stated, must be interpreted as meaning the greatest aggregate advantage to all interests involved. Were it not for the fact that various interests have become well established around the Lake of the Woods, the best use which could be made of the waters of the Lake and of the riparian lands surrounding it, would unquestionably be to give the lake, under control, a range in level at least equal to the greatest range which prevailed under natural conditions, with a view to securing the greatest possible equalization of outflow for the purpose of power development on the Winnipeg River below the outlets of the Lake. The needs of the power interests, however, can be reasonably well met by scientific regulation between much narrower limits than prevailed under natural conditions.

At the Public Hearings, these power interests clearly indicated their present preference for such regulation of the outflow from Lake of the Woods as will result in the greatest possible increase in dependable flow from that lake. While future regulation will not be a *rigid* application of either of the two methods termed by us "Method A" and "Method B," nevertheless, such regulation is bound to be typical of either one method or the other. That is, future regulation will have in view either the increase in *dependable* flow or the increase in *utilizable* flow. If the expressed wishes of the water powers on the Winnipeg River are met, the aim of future regulation of the outflow from the Lake of the Woods will differ radically from the regulation which has prevailed in the past. The aim will be to increase the dependable flow rather than to maintain the level of the lake as nearly uniform as possible throughout a series of years. Through an increase in outflow capacity, however, it will also be possible to effect a substantial equalization of levels during the open season.

Certain power interests on the Winnipeg River have expressed themselves as opposed to the use of auxiliary steam power during protracted periods of low water. This means that for some time at least they desire regulation of the type which we have termed "Method A" and which aims to increase the dependable flow as opposed to the average utilizable flow. A large dependable flow means large reservoir storage capacity. Such storage capacity, while it may, in part, be secured on Rainy Lake, the lakes above Kettle Falls, and on minor storage lakes, must, in the main, be secured on the Lake of the Woods itself, on account of the relatively large area of that lake as compared with the area of the other storage lakes. A large amount of storage on Lake of the Woods means a considerable range in level. This may be secured by either a high maximum level or a low minimum level or both, although the range may still be considerably less than that which prevailed under natural conditions.

The power interests at the outlet of Rainy Lake have already installed machinery for the utilization of considerably more than the greatest possible dependable outflow from that lake which can be secured from the greatest probable future storage. These interests in the future, as in the past, will no doubt desire to secure the greatest possible increase in flow within the limits of its utilization by the machinery already installed, when coördinated to the demand upon the output of the mills and the power plant. That is, future regulation on Rainy Lake, to best subserve those interests, will be of the type which we have termed "Method B."

EXCESS STORAGE vs. INCREASED OUTFLOW CAPACITY

It has already been indicated that in the case of Rainy Lake, it is impracticable to require a definite rate of outflow to be maintained in time of flood as long as the lake stage remains above any given predetermined level. A considerably higher than natural outflow capacity can be advantageously utilized, however, and the necessity for excess storage in time of flood greatly minimized if not entirely eliminated.

In the case of the Lake of the Woods, the tailwater level is dependent merely upon the discharge from the Lake and is not subject to backwater conditions from tributaries below. In view of this fact, it will be possible to provide and utilize a certain outflow capacity whenever the lake has reached a given level and to utilize this capacity to the extent of maintaining a given discharge at times of extraordinary inflow until a predetermined lake stage has again been reached.

The securing of increased outflow capacity necessitates considerable rock excavation, and the increased discharge from the lake results in increased tailwater levels. The greater the outflow capac-

ity, the less the reserve storage capacity required, i. e. the smaller the amount of excess water which must be temporarily stored on the lake because it cannot be discharged as rapidly as it runs in. For example, a discharge capacity of 48,000 c. f. s. would, during the 1916 flood, have necessitated about 1 foot less excess storage than an outflow capacity of 40,000 c. f. s. The exact difference would be dependent somewhat upon the storage on the Upper Rainy watershed and the ordinary rate of discharge from those reservoirs.

If full compensation is given for a flowage easement over all lands flooded or injuriously affected by even the highest occasional stage, then an increase in outflow capacity from 40,000 to 48,000 c. f. s. will, by reducing the excess storage by about 1 foot, permit of an increase of nearly an equivalent amount in the ordinary maximum level without additional compensation to riparian owners. An increase of 1 foot in range of level on Lake of the Woods means an increase of about 750 c. f. s. in dependable outflow, varying of course, with available storage and methods of regulation on Rainy Lake and Lake of the Woods. This is equivalent to an increase of about 20,000 h. p. in the potential water-power on the Winnipeg River. It is apparent that the cost of securing the increased outflow capacity, together with such damage as may result to navigation and power interests at the outlet, and to riparian owners on the Winnipeg River below the outlets, would be clearly overbalanced by the value of the power which can be secured by means of the additional range in stage.

As a reasonable amount of reserve storage capacity must be provided, however, in order to take care of sudden increases in lake level due to excessive precipitation on the lake area itself and on the rocky portions of the watershed immediately tributary, it is not believed desirable to increase the outflow capacity at the ordinary maximum level or reservoir-full stage to more than about 48,000 c. f. s.

If, on the other hand, the range in levels were not changed, notwithstanding an increase in discharge capacity, the smaller amount of excess storage necessary would result in either a reduction in the amount of land required for flowage or else both ordinary maximum and minimum levels could be increased and, consequently, the cost of excavation in navigation channels and in the headraces of the power plants at the outlets could be diminished.

In view of frequent rises in lake level as the result of wind and in view of occasional rises in ordinary level as the result of flood inflows coupled with wind effect, it would appear that the injurious effect of any given regulated level would be limited to about 2.75 feet above the ordinary maximum stage, consisting of 1.25 feet for excess storage in time of flood, and of 1.50 feet for seepage and wind effects. That is, for example, if compensation were offered to elevation 1064 the ordinary maximum level might be placed at 1061.25.

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ENLARGING THE OUTLETS

Under existing physical conditions the discharge capacity of all the outlets of the Lake of the Woods at a level of 1061, including water discharged through the power plants, is approximately 32,000 c. f. s. Most of the increased outflow capacity necessary for satisfactory regulation can best be secured through rock excavation in the Western Outlet in the vicinity of the Canadian Pacific Railway bridge and the site of the old Rollerway Dam. The cost of excavation increases rapidly with increased outflow capacity secured. It does not appear economical to attempt to secure more than an aggregate of 47,000 c. f. s. outflow capacity at a stage of 1061. Of this amount about 40,000 c. f. s. discharge capacity can be secured in the Western Outlet through about 45,000 cu. yds. of rock excavation. About 2000 c. f. s. can be discharged through the Keewatin Flour Mills and 500 to 700 c. f. s. through the old Keewatin Lumber & Mfg. Co's headworks which should be replaced by a permanent structure and the approach channel cleaned out. The Kenora Power Plant in the Eastern Outlet can be slightly remodeled and the channel enlarged so that about 4500 c. f. s. can be discharged through this outlet. By excavating above the present plant and then building permanent headworks to control the flow, the uncompleted portion of the plant can be remodeled and enlarged to permit placing three modern vertical-shaft, high-capacity turbine units. This would substantially increase the capacity of the plant under all ordinary conditions and would more than compensate for the loss of power resulting from possible high tailwater stages if flood discharges ever become necessary in the future. By delaying the installation of machinery the channel provided could be advantageoulsy used for the discharge of water from the lake during the enlargement of the Western Outlet so that in all probability this work could be done in the dry.

A discharge capacity of 47,000 c. f. s. at a stage of 1061 will give a capacity of 48,000 c. f. s. at 1061.25. While the discharge capacity would increase further with increased lake stage it appears best to definitely limit the discharge to 48,000 c. f. s. This would also limit the flowage line in the river below the outlets and permit improvements to be made under fixed conditions. Moreover, if good foresight is exercised it will never be necessary to utilize a discharge capacity of even 48,000 c. f. s. so that there would be no return from investments in flowage rights for higher discharges.

THE CONTROLLING WORKS

The regulation of the outflow from the Lake of the Woods involves the use of controlling works. The present Norman Dam in the Western Outlet is well adapted to such use. Although built for power purposes it has sufficient wasteway capacity to discharge all

the flood water that need ever be drawn from the lake through this outlet.*

Inasmuch as any power plant operating at the Norman Dam site might reasonably be expected to provide sufficient wasteway capacity in the dam to pass the natural flood flow of about 29,000 c. f. s. at a lake stage of 1061, only an additional wasteway capacity of 11,000 c. f. s. would be required in the event that existing wasteways or flumes of equivalent capacity are in the future utilized for water-power purposes. Although the necessary channel enlargement and higher lake levels than prevailed under natural conditions would enhance the value of the Norman Dam as a water-power site by increasing the available head, the discharge of more water than would pass through the Western Outlet in a state of nature would decrease the head and to that extent depreciate the water-power value of the site.

However, if all the power plants at the outlets are willing to forego the small increase in head resulting from maintaining the level of the lake as close to the ordinary maximum stage as possible, well into the spring, and will agree to the drawing down of the reservoir in anticipation of spring floods no extreme high rates of discharge will ever become necessary and the value of the Norman Dam as a power site will be correspondingly increased. Such regulation would clearly appear desirable as it would make a power development at the Norman Dam reasonably feasible, particularly for manufacturing purposes. An occasional reduction in available power due to low head in time of flood discharge is not such a serious consideration for manufacturing plants as it is for hydro-electric plants.

In case a power plant is to be installed at the Norman Dam the best procedure would appear to be to remove the leaky rock fill and then to build the power plant in this location using the present sluiceways as wasteways for controlling the flood water.

DEPENDABLE OUTFLOW FROM LAKE OF THE WOODS

As previously stated, water-power interests on the Winnipeg River have expressed a decided preference for such regulation of the outflow from Lake of the Woods as will give them, for at least many years to come, as large a dependable flow as possible. They have also indicated, that in the distant future, after all of the available power sites on the river have been developed, regulation to increase the utilizable flow so as to permit the installation of additional hydro-electric machinery at all of the sites, in conjunction with auxiliary steam power plants, as against regulation to increase the dependable flow, *may possibly* become the more desirable method of regulation.

* Report of Consulting Engineers (Plates) Plate 27.

In endeavoring to determine an ordinary maximum stage and range of levels which will result in the greatest aggregate benefit to the various interests using the waters of the Lake of the Woods and the shores and harbors thereof, it is desirable to have in mind the reasons why a large dependable outflow will probably make any radical change in the future regulation undesirable. The present or near future requirement by the Winnipeg River power interests of a large, dependable flow, arises from the fact that, leaving load factor out of consideration for the moment, hydro-electric machinery is being installed with a view to using only the regulated flow of the stream which can be depended upon with certainty throughout the most abnormal period of dry years. As the expenditure required in the construction of a water power plant consists very largely of development expense, lands, flowage and rights of way for transmission lines, railroads, highways, construction plant, cofferdams and excavation, and of permanent structures such as dams, the cost of the water-power development *per h. p. of installation and output* reduces rapidly with any increase in the total turbine capacity installed.

The greatest turbine capacity which it would appear feasible to install for the purpose of utilizing outflow from the Lake of the Woods alone in power development on the Winnipeg River under any method of regulation is 16,000 c. f. s. With such an installed turbine capacity and with 100 billion cu. ft. of storage capacity on the Upper Rainy watershed and 5 feet draft on Lake of the Woods, an average flow of about 14,750 c. f. s. could be utilized. Under these conditions, the low water flow in a series of dry years might drop below 8000 c. f. s. and an auxiliary steam or other power plant would have to be available to supply the deficiency in power developed from the low-water flow. If a dependable flow of only 8000 c. f. s. could be secured, the cost of water-power, *per h. p. output*, developed by an installation using up to 16,000 c. f. s. when available, averaging 14,750 c. f. s., would be only about 75% of the cost for an installation using a dependable flow of 8000 c. f. s. If, however, the dependable flow were increased to 12,000 c. f. s. the cost of water-power, *per h. p. output*, produced by the 16,000 c. f. s. installation would be about 95% of that produced by the 12,000 c. f. s. installation. If primary power* is being considered the 16,000 c. f. s. installation would require a large steam auxiliary plant. The 12,000 c. f. s. installation would require none.

The greater the dependable flow, the less the probability of a change in method of regulation being desired in the future by the water-power interests on the Winnipeg River. If a dependable flow of 11,000 or 12,000 c. f. s. can be secured, there is little proba-

*By primary power is here meant power which is available during all hours of all days of all years.

bility of a radical change in method of regulation being desirable in the future. On the other hand, if a dependable flow of only 8000 or 9000 c. f. s. can be secured, it is certain that a change in method of regulation will ultimately be required. Such a change, while affecting primarily the interests in Canada, would be difficult to make, as it doubtless would not be required nor desired by all of the water powers on the River at one and the same time.

In the "Advance Sheets" edition of our Report we expressed a preference for the method of regulation which aims to increase the utilizable flow—that is, "Method B" for both Rainy Lake and Lake of the Woods. In the light of additional information presented at the Public Hearings, however, it appears that while "Method B" is clearly preferable for Rainy Lake, "Method A" is the more desirable for the Lake of the Woods for the present, and also for the future if a *sufficiently large dependable outflow can be secured.*

A large, dependable outflow requires a large reservoir storage capacity. On page 216 of this Report we have added a table showing the dependable outflow from Lake of the Woods which could be secured by forty-two different combinations of methods of regulation and available storage on the Upper Rainy reservoirs and on the Lake of the Woods. It is apparent from this table that the dependable outflow from Lake of the Woods is intimately related to the average regulated discharge from Rainy Lake. A moderately low rate of discharge from Rainy Lake—that is, about 8000 c. f. s.—is most advantageous to an increase in dependable outflow from Lake of the Woods. It appears, further, that an increase in storage on the Upper Rainy watershed is more effective in increasing the dependable outflow from Lake of the Woods for all drafts on storage in that lake exceeding 5 feet if the additional storage over and above 100 billion cu. ft. is used from year to year as required, than if it is held merely for the purpose of increasing the extreme low-water flow from Rainy Lake. This is well shown by the mass curve, Plate 135B and the table on page 216.

ADVANTAGES OF VARIOUSLY STORING WATER

In securing an increase in dependable outflow from the Lake of the Woods, water stored directly on that lake has the greatest value, because it is certain to be available at the right time. This reservoir may be designated the "primary reservoir." Inasmuch as water stored on Rainy Lake can so readily be released and will so soon reach the Lake of the Woods, storage on that lake, at least if the outflow is regulated according to "Method B," possess equal value with storage on Lake of the Woods itself. Storage in Namakan Lake is not quite as valuable, because the discharge capacity, when the reservoir is nearly empty, is limited. The difference in value, however, is relatively small. The Rainy Lake and Namakan Lake reservoirs will be referred to as "secondary reservoirs."

Storage of water in minor storage lakes, a considerable distance above the Lake of the Woods, is not as desirable as storage on that lake. Although it will, no doubt, usually be possible to deliver the available water from these lakes to the Lake of the Woods when needed, nevertheless, as a result of irregular precipitation, the minor reservoirs may not all be full at the critical time. A system of regulation which would insure the water in the minor reservoirs being released whenever, after about midsummer, it could readily be held in the primary or secondary reservoirs below, would come about as near as possible to making such stored water available in full measure for increasing the dependable outflow from the Lake of the Woods.

Another circumstance which tends to depreciate the value of storage on the smaller lakes, to some extent, is the increase in inflow into the primary reservoirs in flood times as a necessary consequence of holding these storage lakes, during the various seasons of the year, at higher than natural stages. The reserve storage capacity required on the primary or secondary reservoirs to absorb the increased rates of inflow must be deducted from the capacity of the minor reservoirs in arriving at the effective storage capacity of these reservoirs. Moreover, the natural equalizing effect of the lakes constituting these reservoir sites must be considered in arriving at the effective storage capacity of the minor reservoirs. In no instance can the available storage capacity of these reservoirs be determined on the basis of depth of storage between extreme low water and the flowage line. The effective depth of storage varies with a number of conditions. It cannot be exactly determined unless long-time records of inflow into the natural lakes are available. This is not the case on the Upper Rainy watershed. An approximation to the effective depth of possible storage on these lakes can be derived by estimating the stage in the lakes, at the beginning of the extreme dry spell, from one to three weeks (depending on their location) before Rainy Lake and the lakes above Kettle Fallshave fallen to the stage at which stored water will be drawn upon, and subtracting this from the stage corresponding to a full reservoir. It is evident from this that the effective storage capacity of most lakes at ordinary high-water mark in a state of nature is relatively small. The principal storage must be secured by raising the lakes to higher stages than natural high-water mark. With Rainy Lake at a stage of 497 Public Works datum only about 2 to 4 feet out of a total draft of from 7 to 9 feet represents effective storage, over and above that provided by nature, which, under the most favorable regulation, could serve to increase the dependable outflow from the Lake of the Woods.

When operated to alleviate extreme flood conditions on the primary reservoirs, the minor storage reservoirs would be kept as nearly empty as possible except in the occasional year of extreme flood.

When operated to aid in increasing the dependable outflow from the primary reservoirs, the minor reservoirs would be kept as nearly full as possible until the water was needed in the primary reservoirs. When so operated, the minor reservoirs would be full after the spring break-up except during the occasional period of extreme drought, and hence would necessarily increase the flood inflow into the secondary reservoirs.

The construction of dams on lakes far removed from railways, highways, or waterways is necessarily expensive, and the smaller the reservoir, the greater the relative cost of operation and maintenance. The structures must usually be built of rock-filled timber cribs which may require replacement even before the stored water has once been of service. Unless great fluctuation in level above the ordinary flowage level is to be permitted, almost constant attendance is required at the dam.

A few of the larger unutilized lakes are undoubtedly worthy of further and more detailed study, and will very probably be found to constitute desirable storage sites. With this possibility in view, it would appear desirable for each Federal Government, respectively, in granting patents to riparian lands on lakes which later may possibly be utilized as storage reservoirs, to retain a flowage easement over such lands up to, say, 5 feet above the natural extreme high-water level of these lakes or to such other level as upon examination may appear most desirable. Such action would fully safeguard future interests in the utilization of these waters for power and navigation purposes. In the future, when authorizing the construction of dams at the outlets of such lakes, the Governments might, if they so desired, require payment of an amount representing the depreciation in value of the riparian lands resulting from the attachment of the flowage easement.

It is probable that the increase in dependable outflow from Lake of the Woods through storage of water in minor reservoirs must remain an incidental benefit, and subject to the advantageous local use of the water flowing from these reservoirs for power purposes whenever such use is practicable and economical.

The use of the minor storage lakes for local water-power developments would result in a reasonably satisfactory increase in utilizable outflow from the primary and secondary reservoirs.

The use of the smaller storage lakes in connection with logging operations need not be detrimental to power development, as it has frequently been in the past, provided the closing of the controlling dams in the fall or winter, or any time before the beginning of the spring break-up is prohibited. Under proper regulation, the storage of water for advantageous use in logging operations may be made beneficial to the use of the water for power purposes.

NEED FOR REGULATING OUTFLOW FROM LAKE OF THE WOODS

The power plants on the Winnipeg River require assurance of an increase in dependable flow during such low-water years as are likely to occur at any time, and also during the winter of most ordinary years. The Winnipeg Electric Railway Company's plant on the Pinawa Channel with an installed turbine capacity of 34,000 h. p. cannot use more than 8,000 c. f. s. The City of Winnipeg plant, however, with an installed capacity of 47,000 h. p. can utilize about 11,500 c. f. s. at 100% load factor, although the greatest demand in the past has been substantially less than the installed capacity of the plant. The ultimate installation at this plant will be just about double the present installation. During the last year, the peak load demands of Winnipeg and vicinity have just about equaled the capacity of the existing water-power installations; but as the two systems are not interconnected, the Street Railway Company has had to supplement the hydroelectric power with steam power. To meet this demand, an additional water-power plant is under construction at Du Bonnet Falls.

During the spring of 1911, the flow of the Winnipeg River below the mouth of the English, dropped to 12,000 c. f. s. The outflow from Lake of the Woods at this time was about 8,000 c. f. s. Later, however, the outflow from the Lake of the Woods dropped for several months to about 5,200 c. f. s. Due to a much larger contribution from the English River, at this time, the flow of the Winnipeg River dropped only slightly below 14,000 c. f. s. during the winter. There is no assurance, however, that without regulation the minimum flow would not be reached simultaneously on the two streams. In fact this is exactly what would have occurred in a state of nature in 1911. Such a minimum flow would cause a shortage of water which would virtually result in a paralysis of many of the industries of the City of Winnipeg and thus emphasizes the need for the prompt establishment of a scientific system of regulation.

According to the table on page 216 of this Report an increase of 50 billion cu. ft. in storage on the Upper Rainy watershed, assuming a regulated rate of outflow of 10,000 c. f. s. will result in an increase of not less than 360 c. f. s. in dependable outflow from Lake of the Woods. On the whole, the greater the storage, the less the increase in dependable flow from any given addition of stored water. So long as the increase in dependable flow, however, is worth more than the cost of securing the additional storage required to produce that increase in flow, it would appear desirable to provide increased storage. As previously indicated, storage on Lake of the Woods, Rainy Lake and the lakes above Kettle Falls is of practically equal value in increasing the dependable outflow from Lake of the Woods. Storage on minor lakes whose outlets are feasible water-power sites is

impracticable, and storage on other minor lakes is of less certain benefit than storage on the principal reservoirs themselves.

A FLEXIBLE MINIMUM

About twenty-five years' runoff records are available as the basis for determining desirable levels and methods of regulation for the Lake of the Woods. There is no assurance, however, that greater extremes of hydrological phenomena will not occur in the future. Provision must therefore be made for such contingencies. Extreme flood conditions may be controlled by means of increased outflow capacity and excess storage or flood reserve. The effects of extreme droughts can only be overcome by the use of stored water. The very expression "dependable outflow" implies sufficient storage to substantially maintain the given rate indefinitely into the future. Having adopted a fixed maximum stage, the only way that any given rate of outflow can be made truly dependable is by providing a flexible minimum level. The minimum which may be reached under all ordinary conditions may be clearly stated but provision should be made for additional drafts on stored water in case unprecedented hydrological conditions should occur in the future.

USES OF UPPER RAINY STORAGE

If a total of 150 billion cubic feet of storage is provided on the Upper Rainy watershed and this storage is utilized primarily for equalizing the outflow from Lake of the Woods and maintaining a certain level on that lake it would increase the available power at Fort Frances and International Falls above that now available by about 700 h. p. making a total of about 30,000 h. p. on the Rainy River when the potential power of about 9,000 h. p. at the Long Sault Rapids is added, and it would increase the potential water-power on the Winnipeg River by nearly 50,000 h. p. or about 20% more than that which would be available on this stream with the natural outflow from Rainy Lake and a range of about 6 feet in the level of the Lake of the Woods.* Assuming the entire 150 billion cu. ft. of storage capacity on the Upper Rainy watershed utilized primarily for the purpose of increasing the available water-power on the Rainy River, then there would be an increase of about 2,200 h. p. at International Falls and Fort Frances over that now available, making an aggregate of about 32,000 h. p. on the Rainy River when the potential power at the Long Sault Rapids is included, and an increase in the total potential water-power on the Winnipeg River of not less than 17,000 h. p. over what would be available with the natural outflow from Rainy Lake. Further increases in storage capacity result in additional increases in dependable outflow from the Lake of the Woods and Rainy Lake and while there will be decreasing returns from further investments in storage, the limit of

* Throughout this discussion it should be borne in mind that the power interests at International Falls-Fort Frances have represented that they could immediately utilize additional storage on Rainy Lake; while, on the other hand, the Winnipeg River power interests have represented that they could not, for some years to come, utilize such additional storage.

economical development possibly will not have been reached until more than 200 billion cublic feet of total storage capacity will ultimately have been provided on the upper watershed.

The more the inflow into the Lake of the Woods is equalized the more readily can the recommended level be maintained within a small fluctuation, and the greater is the dependable outflow that can be secured from any given extreme range in level of the Lake of the Woods. The principal storage reservoirs available for equalizing the inflow into the Lake of the Woods are those already constructed by private capital on Rainy Lake and the lakes above Kettle Falls. On Rainy Lake there is, at present, 70 billion cu. ft. of storage available between the levels of 497 and 490 and on Namakan and adjoining lakes above Kettle Falls there is 30 billion cubic feet available between the levels of 508.5 and 497.

It is to the interest of the International Falls and Fort Frances plant to use water at a rate of about 10,000 c. f. s. whenever stored water is available and there is a market for the product of the mills. As the runoff from the watershed tributary to Rainy Lake amounts to 60% of the total runoff from the Lake of the Woods watershed, and a rate of discharge of 10,000 c. f. s. from Rainy Lake is between 80% and 90% of the rate at which water will ordinarily be discharged from Lake of the Woods under regulation, it is apparent that the Upper Rainy reservoirs will ordinarily be only partially full when the Lake of the Woods reservoir is completely full. As a consequence, the probabilities are that if water is being drawn from Rainy Lake at an average rate of 10,000 c. f. s. that the lake will not be full at the beginning of a series of dry years, even though Lake of the Woods would be full under the same hydrological conditions. If water is being drawn from Rainy Lake at an average rate of about 10,000 c. f. s. the available 100 billion cu. ft. of storage on the Upper Rainy watershed will be of relatively little service in increasing the *dependable outflow* from Lake of the Woods although it will reduce the ordinary fluctuation in the level of that lake by materially equalizing the inflow into the lake. The records of the past 24 years indicate that if the outflow from Rainy Lake were reduced to approximately 8000 or 8500 c. f. s. whenever stored water was being drawn upon, both Rainy Lake and Lake of the Woods would be full at the beginning of a dry spell and the dependable outflow from the Lake of the Woods would be increased by substantially 1000 c. f. s. or 10%, with a corresponding increase in the potential water-power on the Winnipeg River of about 25,000 h. p. and a loss of substantially 1,000 h. p. at International Falls and Fort Frances.

The dependable outflow from Lake of the Woods, however, can also be increased by additional storage on the Upper Rainy watershed. This additional storage will not only benefit the water powers on the Winnipeg River, but it will also aid in maintaining the recommended

level on the Lake of the Woods and increase the available water-power at International Falls and Fort Frances. The most economical way to secure additional storage, considering both the probable cost of flowage rights, impounding works, etc., and the resulting benefits, appears to be to raise both Rainy Lake and the Lakes above Kettle Falls. By raising Rainy Lake to an ordinary maximum level of 499.5 with 0.5 ft. of reserve storage capacity and Namakan and adjoining lakes to about 515, an additional 45 billion cu. ft. of storage capacity can be secured. By drawing Rainy Lake down another half foot, that is to 489.5, which is about 3 feet above natural extreme low-water, a full additional 50 billion cubic feet of storage can be secured.

If water is being used at the outlet of Rainy Lake at an ordinary rate of 10,000 c. f. s. this additional storage would increase the available water-power on the Rainy River by about 2500 h. p. or about 10 per cent. It would directly increase the dependable outflow from Lake of the Woods under a 5 or 6 foot draft by not less than 360 c. f. s. This is equivalent to the increase in outflow which could be secured by half a foot of additional draft on the Lake of the Woods. Indirectly, the additional storage capacity of 50 billion cu. ft. by further equalizing the inflow into the Lake of the Woods, would assist in maintaining any given level on less ordinary fluctuation. Moreover, it would also reduce the occasional extreme flood stages on Lake of the Woods, thus permitting the maintenance of an ordinary maximum stage on that lake about 3 inches higher than could be maintained with the present storage on the Upper Rainy watershed, without encroachment on the margin of safety provided by flowage rights acquired to any given contour above the ordinary maximum stage. The net result, then, of an additional 50 billion cu. ft. of storage on the Upper Rainy watershed would be an increase of 2,500 h. p. in available water-power on the Rainy River and an increase of over 500 c. f. s. in the dependable outflow from Lake of the Woods, corresponding to an increase in the potential water-power on the Winnipeg River of at least 15,000 h. p. besides reducing the ordinary fluctuation in the level of the Lake of the Woods.

The use of the Upper Rainy storage for the purpose of maintaining an ordinary rate of outflow of 10,000 c. f. s. from Rainy Lake instead of about 8,000 c. f. s. assists in preventing the Lake of the Woods from exceeding its ordinary maximum level in time of flood, because a greater amount of storage capacity is always available for the storage of flood-water even without water having been wasted in anticipation of flood inflows. Greater storage capacity reduces the rate at which it is necessary to discharge the flood-water after the reservoir is full, or the excess water to be stored on the lake above the ordinary maximum stage. The restriction of the ordinary rate of outflow from Lake of the Woods to a dependable rate of about 11,000 c. f. s. on the

other hand, results in maintaining that lake at substantially its ordinary maximum stage about twice as large a proportion of the time as Rainy Lake. This reduces the amount of storage capacity ordinarily available on the Lake of the Woods to a very small amount. As a consequence, more flood reserve or capacity for temporarily storing flood-water *above* the ordinary maximum stage must be provided. Moreover, the discharge capacity of the Lake of the Woods, even with the outlets enlarged as recommended, is relatively smaller than that of Rainy Lake. Since the flood-water cannot be discharged as rapidly and since less capacity for storing flood-water *below* the ordinary maximum level is ordinarily available, provision must be made for the storing of more flood-water *above* the ordinary maximum level on Lake of the Woods than on Rainy Lake. In other words, 1.25 foot of flood reserve on Lake of the Woods affords about the same margin of safety as 0.5 foot on Rainy Lake.

Another factor influencing the amount of flood reserve to be provided on any given lake is the relation between the maximum natural rate of inflow and the maximum natural rate of outflow. A relatively small lake usually has a maximum natural rate of outflow equal to its maximum rate of inflow. On such a lake no increase in outflow capacity is required under regulation; neither is a flood reserve required. This is substantially the condition on Namakan Lake, for example. On the other hand, a lake whose area is large in comparison with the area of its tributary watershed, other conditions being similar, always has a maximum natural rate of inflow greatly in excess of its maximum natural rate of outflow. On such a lake the outflow capacity must be increased or a large flood reserve must be provided, or both.

The maximum natural rate of inflow into the Lake of the Woods was more than twice the maximum natural rate of outflow. The maximum natural rate of inflow into Rainy Lake was only about 35 per cent greater than the maximum natural rate of outflow, hence much less flood reserve is required on this Lake than on Lake of the Woods.

Still another consideration affecting the amount of flood reserve required for a given margin of safety is the character of the watershed. Here, again, the advantage lies with Rainy Lake. Melting snow and rain drains off from the watershed directly tributary to the Lake of the Woods very much faster than from the Upper Rainy watershed. This is well illustrated by the conditions that prevailed during the 1916 flood. The maximum natural rate of inflow into the Lake of the Woods would have occurred during the last ten days of April when Rainy Lake, under natural conditions, with more than half the tributary watershed, would have contributed less than one-fifth of the total inflow. On the other hand, the maximum natural rate of inflow into Rainy Lake occurred during the last ten days of

May. At the time when, under regulation, Rainy Lake would be discharging its maximum, the flood from the local watershed tributary to the Lake of the Woods would be long past. Under regulation the maximum rates of inflow into Lake of the Woods will occur long before the maximum regulated outflow from Rainy Lake reaches this lake, therefore, if storage is provided for these waters there will be no difficulty experienced in taking care of the regulated outflow from Rainy Lake.

REGULATION BELOW ORDINARY HIGH-WATER MARK

In connection with the right of the Federal Government of the United States to hold natural lakes at *ordinary high-water mark* in the interest of navigation, it may here be remarked that such regulation will inevitably result in raising the lake to a high level, substantially higher than extreme high-water mark under natural conditions, unless the discharge capacity of the outlets of such lakes is increased by excavation to an extent considerably greater than such outlets are obstructed by the impounding dam. But an increase in the flood discharge from a lake results in exceeding even the extreme high-water mark in the channel below the outlet, consequently, the right to regulate a lake within its ordinary high-water mark can practically never be exercised without trespassing upon the rights of the owners of land bordering the stream into which the lake discharges. The artificial raising of the level of a lake *at any time of the year* inevitably results in unauthorized trespassing upon the rights of riparian proprietors, either in the lake, or below it, or both, unless a flowage easement is secured. In other words, no regulation of lake levels, whatever, is possible even by the Federal Government of the United States, without the acquisition of *some* flowage rights, because effective regulation within ordinary high-water mark, both n the lake and in the channel into which it discharges, is physically impossible.

Regulation of the level of the Lake of the Woods at or below ordinary high-water mark in the interest of navigation would require a dam such as the Norman Dam, for example, in the Western Outlet of the lake and extensive excavation in the channel approaching the dam, besides the acquisition of flowage rights at the outlets and on the Winnipeg River below. This would cost considerably more than the flowage easement over the low lands along the southern border of the Lake.

If the level of the Lake of the Woods were to be regulated for the sole purpose of benefiting navigation, this end could be most economically attained by acquiring flowage rights to about elevation 1062 and maintaining an ordinary maximum level between 1059 and 1060 after danger from spring floods had passed.

APPENDIX I

COPY OF REPORT OF SPECIAL AGENT A. F. NAFF

DEPARTMENT OF THE INTERIOR,
GENERAL LAND OFFICE,
Crookston, Minn., Dec. 12, 1895.

Hon. COMMISSIONER, G. L. O.,
Washington, D. C.

SIR: I have the honor to report, in obedience to your instructions letter "P" #52,288, dated September 10th, 1895, that during the month of Nov. just passed I made examination of the overflow of the Lake of the Woods as shown in my weekly reports for said month. I arrived at the lake on the 8th and found the ice was commencing to form so that it was with some difficulty that I could get around in a boat. However, I proceeded to make investigations and see the Indians and old settlers and procure such reliable information as I could get in the way of oral statements and affidavits. The letter being a part of my report and herewith attached. I found from the information from others and the observations I made that the present stage of the water is an abnormal one and the source of much dissatisfaction and complaint on the part of the citizens living in the vicinity of the lands claimed to be damaged by the high water. Old settlers admit that there has always been a periodical rise and fall of the water in the lake, but claim that since the dam was put in by the Canadian Government at the Western outlet of the same at Rat Portage in the year 1888, the water has been raised and held up about three feet higher than its natural stage and has consequently overflowed and rendered unavailable and useless thousands of acres of valuable land on the South shore and within the United States territory. Some of those in evidence claim that before the dam was built in 1888 they could, and did many times, walk and drive along the shore on a sandy beach from the mouth of Rainy River on the East to the International boundary line on the West. They also claim, and said they could show evidence that trees were once growing on dry land where the water is now two or three feet deep and extending inland for nearly one mile from where the live trees once stood. I saw stumps and trunks of trees myself under water as you will see indicated on map No. 1 and might have seen more as I was told but for the ice, which was covered with snow except here and there where the wind had blown and drifted it away. In going out the ice was too thin to allow me to go far and too thick to allow me to get along to much advantage in a boat. I broke through the ice and went into the water in my efforts to make some of the examinations that I desired. I failed to get to the North West Angle. I started once to go there, on foot on the ice, near the shore, and all the way to Rat Portage, and had gone five miles, to Mr. Springsteels, on Poplar point, on my way, but the Indian, Ka-wa-kas-ka-ne-to-wa, whom I had employed as guide and assistant, in carrying my pack, deserted me, and as I could get no one else to venture across with me I had to turn back and, as my weekly reports show, get to the railroad and reach Rat Portage in that way. At Rat Portage I found the dam, that was built by the Canadian Government across the Western outlet of the lake, in the year 1888, still intact with the exception, that, at a high stage of the water at some time, the top part had been washed away, but still leaving enough in place to hold the water up some three feet above what the normal level of the lake would be under natural conditions. This statement you will notice is corroborated, to some

extent, by the statements made in the affidavits taken at Rat Portage and herewith attached. On map No. 1 you will see I have indicated, as well as I could, from a preliminary examination about where the overflow is. This is indicated by the red ink delineations. I also enclose map No. 2 to show you the north portion of the Lake of the Woods with Rat Portage and the Canadian Pacific R. R. Map No. 3 will show you on a larger scale the location of the old dam in question as well as the new dam now about completed by the Keewaten Power Company. The information given on the upper right hand corner of Map No. 3 is as much as I learned in reference to it. I went to see it and discovered that as it now stands, and even with a considerable more rise of the water, from timbers not yet put in, the level of the lake will not be affected. But I was informed that when this new dam is closed up to its fullest capacity it would raise the water about three feet higher in the lake than its present level caused by the old dam. The company claims however that they think it will never be necessary for them to use the dam to its fullest capacity. From the best information I could get, in connection with my own observation, I am inclined to the opinion that a closer examination and survey, to determine the extent of the natural overflow of the lake over our territory, would reveal the fact that from 25,000 to 40,000 acres of valuable land has been destroyed and damaged. Some of this land is fertile and much of it has in time yielded rich crops of grass which has been cut and saved by many who can testify to the same. I send some newspaper clippings with my report which will show the sentiment of the people interested in reference to the flowage question. The General Land Office department has had many complimentary notices, irrespective of party, for the interest it is manifesting in this matter and the hope is entertained, especially by those most affected by the damage already claimed and the fear of more to follow, that some relief will come through its intervention. I have conferred with parties who are able to advise and am informed that the month of May will be the best season of the year to make a critical examination of the condition and extent of the overflowage and the amount of damage done upon which to base a plea of complaint and for relief. Respectfully submitting the above for your consideration and advisement, I am,

With much respect,

Your obedient servant,

(Sd.) A. F. NAFF,
Special Agt. G. L. O.

STATE OF MINNESOTA, } ss:
County of Beltrami. }

Chief Maypok, being duly sworn according to law, says, I am about 49 years of age and have lived at Warroad Indian Village, on the South shore of Lake of the Woods, all of my life. I have been all over the Lake of the Woods and especially along its South shore and am well acquainted with it as it is now and as it has been for over twenty years past. I know that within the last past eight years the water has been raised several feet on the said lake from some cause. I have never kept any measurement of the rise of the water but know that at one time I could walk on the beach of the original lake shore all the way to Rainey River on the East and to the Northwest angle on the West and North. Trees and bushes were at that time, eight years ago, growing along this original beach but are now broken and fallen down and lying in the water. The water extends inland from one-half mile in some places to as much as two or three miles in other places. Logs and brush have been driven inland from the old beach as far as a mile in some places. Before the rise of the water in the lake there were three small streams or outlets at the mouth of Warroad River, but now it is one solid sheet of water overflowing the low land at the mouth of the river for at least three quarters of a mile from its mouth. At the time I am speaking of, that is seven or eight years ago, I could touch the bottom of the Warroad River at and near its mouth, with a paddle, but now I can not reach the bottom with my paddle. The land that is overflowed around the shore as above mentioned is good rich land and at one time

had fine crops of grass on it which made good hay. My understanding is that the dam built by the Canadians at the outlet of the lake has been the cause of the water rising in the same. I know that a short time after they commenced building the dam the water commenced rising.

CHIEF (his x mark.) MAYPOK.

Witness:
GEORGE A. RALPH.
LOUIS AUGNET.

Subscribed and sworn to before me at Warroad River, Lake of the Woods, this 12th day of November, 1895.

A. F. NAFF,
Special Agt. G. L. O.

The following Indians concur in the above as being true and correct:

Ka-ga-geshig (Crow Cloud)	Charley Copeness.
Ka-ga-gis (Little Crow)	Gib. Thunder.
Ash-wash (Chief)	None-guan-ip.

STATE OF MINNESOTA, } ss:
County of Beltrami.

George A. Ralph, being duly sworn deposes and says: My name is George A. Ralph. I reside at Crookston, Minnesota. I am by profession a Civil Engineer and Surveyor; that I have for the last eight years been engaged as U. S. Government Surveyor in surveying lands in the northern part of the State of Minnesota, some of which lie along the shores of the Lake of the Woods; that in making such surveys I have taken particular notice of the condition of the land bordering on said lake as to its being overflowed by waters from the Lake. I observed that this was not a natural condition but was caused by the daming up of the waters in the Lake. I found the land overflowed in places for a distance of two miles back from the natural beach of the lake. I noticed many trunks of fallen trees lying submerged on this overflowed land which were of varieties that indicate the land on which they grow was dry land. I have also noticed that all the streams running into the Lake from the south are overflowed at their mouth to such a depth as to give it the appearance of a bay or inlet rather than a stream. In some instances I found the water backed up these streams for a distance of five or six miles. I am convinced that the swamp lands in the vicinity of the Lake is affected by this overflow for a distance of eight or ten miles back from the Lake.

(Sd.) GEORGE A. RALPH.

Subscribed and sworn to before me at Warroad River, Lake of the Woods, this the 14th day of November, 1895.

(Sd.) A. F. NAFF,
Special Agent, G. L. O.

STATE OF MINNESOTA } ss:
County of Beltrami

Pash-te-tu-wa-scung, or Colonel Wolsley, being duly sworn according to law, says. I am sixty years of age and Manitou Falls, Ontario, is my home. I have been all over Lake of the Woods every year for many years past and am well acquainted with it and its changes both on the Canadian and American shores. I have traveled over the lake in a birch bark canoe and have walked along the beach on the South shore from Buffalo Point to Rainey River on the sand where it is now covered three or four feet with water and the water has covered the low meadow lands around the shore extending, as much as a mile in some places and more in others, inland widening the mouths of the streams so that they look more like lakes than rivers. I have seen where

timber once stood, water covering the logs and stumps and spreading out in every direction so as to destroy hay meadows, islands and other low grounds of much value. I can notice that all this change has come over the lake within the last eight years or something like that. This overflow has been caused by the dam that was built at Rat Portage which I saw when it was first commenced and have seen every year since the work was commenced. Some of the citizens of Rat Portage complained at the building of the dam at said place and tried to get the Indians to object to its construction which they did do but to no effect. The Indians have made complaint to the officials of the Canadian Government about the raising of the water in the said Lake of the Woods and damage it has done to the lands around the same but no notice has ever been made to their appeals. The Indians are universal in their complaint of the damage that has been done to the lands and to them so far as they are acquainted with the circumstances and they all know of it who are old enough settlers and have been acquainted with the lake and its waters for the last past ten years.

PASH-TE-TU-WA-SCUNG (x) or COLONEL WOLSLEY.

Witness:
GEORGE A. RALPH
JANE WHYTE

Subscribed and sworn to at War Road River Lake of the Woods this 15th day of November, 1895.

(Sd.) A. F. NAFF,
Special Agent G. L. O.

STATE OF MINNESOTA } ss:
County of Beltrami

T. W. Love being duly sworn according to law says I am thirty years of age and my post office address is Roseau Roseau Co., Minnesota. I lived at Rat Portage, Ontario, about two and a half years including the time between the fall of 1882 and the summer of 1885 which was before the dam was built at the outlet of Lake of the Woods. I have lived in Rat Portage about a year since 1893 and in July 1894 I came to the War Road River on the South shore of the Lake of the Woods. From the time I was first in Rat Portage until the time I was there last in 1893 I could see the difference in the water of the lake and from observations I made of the water in reference to rocks and the dam that had been built I am satisfied that the water has been raised about two and one half or three feet. There were stationary rocks and islands that I saw were bare and projecting out of the water when I first knew the lake in 1882 to 1885 that are now covered with water. I have been around the lake shore from the Northwest angle to the Rainey River since the summer of 1894 and have observed the effect of the high water overflowing the low lands around the lake on the South side and over territory belonging to the United States Government. I am satisfied from my own observation that much good land has been rendered useless and unavailable on account of the high water and unnatural overflow caused by the dam built by Canadians at Rat Portage, Ontario.

(Sd.) T. W. LOVE.

Subscribed and sworn to before me at War Road River, Lake of the Woods, this the 16th day of November, 1895.

(Sd.) A. F. NAFF.
Special Agent, G. L. O.

PROVINCE OF ONTARIO } ss:
District of Rainey River

J. S. Whiting being duly sworn according to law says. I am 35 years of age and my residence has been at Rat Portage, Ontario, since 1880, which is my post office address. Since the above date I have been on the Lake of the Woods between

Rat Portage and Rainey River in the capacity of Captain and Pilot of a boat and have taken particular notice of different stages of the water in the lake during the intervening time from 1880 down to the present. In the summer of 1880 the water in said lake was six feet lower than it was after the dam was put across the Western outlet of the said lake. The dam refered to was put in during the year 1887-8. The stage of the water in the lake varies from time to time scarcely ever being two years the same. Between the years 1880 and 1887 the water rose as much as 3 feet from natural causes. The water was 3½ feet lower just before the dam was built than it was some few months after the dam was completed. The water in the lake at the present time is about 2½ feet lower than it was at its highest stage within my knowledge. I know the above facts to be true from observations taken from landmarks in and around the lake such as rocks, islands and the high lake shores.

(Sd.) J. S. WHITING.

Sworn and subscribed before me the 27th day of November, A. D., 1895.

G. C. FRISBIE
U. S. Consular Agent at Rat Portage, Ontario.

PROVINCE OF ONTARIO
District of Rainey River } *ss:*

D. C. Cameron being duly sworn according to law says. I am 41 years of age and Rat Portage, Ontario, is my home where I have lived for the last past 12 years. I am engaged in the lumbering business and am interested in a saw mill at Rat Portage. I have been out on the Lake of the Woods more or less in connection with my lumbering business and in a general way I am familiar with the said lake and its conditions and changes on the 12 years last passed. The Lake of the Woods is subject to changes from natural causes and varies in its highth according to the seasons and supply of water furnished from its various tributaries. Some seasons the water is high and at other times it is low. The water in the lake has been kept permanently some higher by the old dam built at the Western outlet than it would be if the same was away. The dam did not raise the water in the lake, at any time since its construction as high as the high water mark now visible on the rocks and high shores around and in the lake. I think the old dam has had the effect of holding the water up at least two feet higher, in the Lake of the Woods, than it would be if the dam was entirely away.

(Sd.) D. C. CAMERON.

Sworn and subscribed before me the 28th day of November, 1895.

G. C. FRISBIE,
U. S. Consular Agent at Rat Portage, Ontario.

APPENDIX II

MISCELLANEOUS BENCH MARKS ESTABLISHED CHIEFLY BY FIELD STAFF OF INTERNATIONAL JOINT COMMISSION

In order to determine a true sea-level datum at each of the camps of the Lake of the Woods Survey a correlation was carried out between each gauge and the gauges at Oak Island and Oak Point. From the elevation thus determined for the zero of each gauge, bench marks, of a more or less permanent character, were established at the sites of many of the camps.

In order to establish a bench mark at Oak Point of a more permanent character than Bench Marks Nos. 1 and 2 described on page 100, the elevation of the centre of the bronze plug marking the International Boundary Survey triangulation station "Oak" was ascertained. This elevation was established from the mean of two determinations made from Bench Marks Nos. 1 and 2.

Bronze plug marking I. B. S. triangulation station "Oak", about 300′ north-west of the fishery. Elevation, Sea-level Datum..... 1073. 645

A list of the bench marks established at the various camps is given below:

NORTH WEST ANGLE INLET:

Harrison Creek; determined from eight days gauge readings; bronze plug in base of the International Boundary Monument No. 924 (new number) situated on the north bank of Harrison Creek. Elevation, Sea-level Datum 1066. 28

Poplar Creek; determined from twelve days gauge readings; spike driven vertically in a cone at the base of a 14 inch poplar blazed on north side; located 10 feet easterly from shore of Creek and 300 feet down stream from the quarter corner of Sections 23–24, Township 168 N., Range 35 W. of the 5th Meridian. Elevation, Sea-level Datum..... 1066. 06

AMERICAN POINT, MINNESOTA:

The bench mark is on a spike driven vertically in a cone at the base of an 18 inch poplar blazed on west side; located at south-west corner of clearing on west side of American Point island, 30 feet east of the intersection of shore line with the north boundary of Section 24, Township 168 N., Range 34 West of the 5th Meridian. Elevation, Sea-level Datum, determined from 14 days gauge readings..... 1063. 71

SUGAR POINT, MINNESOTA:

Bench mark in centre of triangle cut in bare rock, 75 feet north of J. Gould's house in Section 17, Township 167 N., Range 33 W. of the 5th Meridian, about two miles S. W. of Oak Island. Referenced by three arrows in rock, each about 6 inches long, pointing towards the triangle and located as follows:

No. 1 is due north of the △ at a distance of 6 feet.
No. 2 is S. 30° E. of the △ at a distance of 15 feet.
No. 3 is S. 80° W. of the △ at a distance of 15 feet.

The elevation, Sea-level Datum, determined from 15 days gauge readings is..... 1065. 79

STONEY POINT, MINNESOTA:

On the head of a nail driven into a cone on the root of a 12 inch ash tree about 2500 feet north of the southwest corner of Stoney Point, in Section 34, Township 166 N., Range 35 W. of the 5th Meridian. The tree on which this bench mark is placed is on a long sand spit which runs north from Stoney Point. The tree is blazed and the following legend is cut into the blaze: I. J. C., B. M. 1063.48. The elevation, Sea-level Datum, determined from 5 weeks gauge readings is..... 1063.49

A picture of this bench mark is shown on Plate Q.

BIG GRASSY RIVER, ONTARIO:

On the head of a nail driven into a cone cut on the root of a 24 inch elm tree, on the north branch of Big Grassy River about 300 feet north-west of the mouth of the outlet of Lake Eleanor. The tree is blazed and the following legend cut into the blaze: I. J. C. B. M. 1063.69. Elevation, Sea-level Datum, determined from 17 days' gauge readings..... 1063.68

A picture of this bench mark is shown on Plate Q, photograph No. 1.

FALCON RIVER, SHOAL LAKE:

The bench mark is on a spike driven vertically in the cone at the base of a 12″ poplar, located about 600 feet northeast of the mouth of Falcon River and about 300 foet from the shore ot the lake. Elevation was determined from the Greater Winnipeg Water District bench mark, elevation 1064.76. Elevation, Sea-level Datum..... 1065.69

BENCH MARKS ABOVE KETTLE FALLS—MINNESOTA AND ONTARIO

The elevations of the following bench marks were determined by water level transfer from the Manitoba Hydrographic Survey, B. M. No. 2, above Kettle Falls, described on page 89, the elevation of which was re-determined by water level transfer from Ranier, Minnesota, and ascertained to be 506.47, Public Works, Canada, Datum.

On a blazed tree near middle of Overflow Channel No. 2, north of Kettle Falls (see Cross Sections of Overflow Channels, in Atlas), marked B. M. 511.10, established during April, 1913. Approximate elevation, Public Works, Canada, Datum..... 511.10

Station O of Plans for proposed dam on Canadian island at head of Canadian Falls, on 2 inch white pine stub marked only: "B. M." Top 2½ feet above ground. Sixteen feet N. E. of an 18 inch Norway pine which has a blaze towards stub. Elevation given on plans is 509.06. Approximate elevation, Public Works, Canada, Datum..... 509.22

I. J. C., B. M. No. 1. See Kabetogama Lake Sheet:

On a nail on root of tamarack tree on east side of overflow channel section at Gold Portage at west end of Kabetogama Lake on S. W. quarter of Section 19, Township 70, Range 21, St. Louis Co., Minn. Approximate elevation, Public Works, Canada, Datum..... 514.2

I. J. C., B. M. No. 2. See Kabetogama Lake Sheet:

On top of rock at S. E. end of Gold Portage on the north east quarter of Section 30, Township 70, Range 21, St. Louis Co., Minnesota. Approximate elevation, Public Works, Canada, Datum..... 501.9

I. J. C., B. M. No. 3. See Kabetogama Lake Sheet:

On iron bolt leaded into rock, on most easterly point of N. E. quarter of Section 8, Township 69, Range 21, St. Louis Co., Minnesota. Approximate elevation, Public Works, Canada, Datum..... 504.2

I. J. C., B. M. No. 4. See Kabetogama Lake Sheet:

On top of rock on most northerly point of Section 21, Township 69, Range 21, St. Louis Co., Minnesota, located by two blazed trees. Rock is 4.6 feet from larger pine tree and 4.0 feet from smaller one. Approximate elevation, Public Works, Canada, Datum..... 507.6

I. J. C., B. M. No. 5. See Kabetogama Lake Sheet:
On most north-easterly point of north west quarter of Section 30, Township 69, Range 20, St. Louis Co., Minnesota; on top of iron bolt leaded into the rock. Approximate elevation, Public Works, Canada, Datum.. 507. 7

I. J. C., B. M. No. 6. See Namakan Lake Sheet:
On top of rock 70 feet east of point at mouth of inlet in north east quarter of Section 25, Township 69, Range 20, St. Louis Co., Minnesota. Referenced by two blazed pine trees; 11.2 feet from the south one and 13.5 feet from north one. Approximate elevation, Public Works, Canada, Datum. 512. 7

The elevation of the following bench mark was established from the I. J. C., B. M. No. 19, on Six Deer Island, and this latter one was established from M. H. S., B. M. No. 3, below Kettle Falls by combined instrumental levels and water level transfer.

I. J. C., B. M. No. 11. See Namakan Lake Sheet:
On nail in top of tamarack stump on trail across Bear Portage and marked I. J. C. S., B. M. 511.0; established during March, 1913. Approximate elevation, Public Works, Canada, Datum..... 510. 1

Of the following bench marks the elevations of Nos. 12, 13, 14, 15, 16, and 18 were established by water level transfer in October, 1913, from the United States and Canada Boundary Survey bench mark described below as I. J. C., B. M. No. 20.

I. J. C., B. M. No. 12. See Little Vermilion Lake Sheet:
On a step cut in foot of a 16 inch Poplar in the first little bay just below Little Vermilion Narrows on Canadian mainland. Approximate elevation, Public Works, Canada, Datum..... 507. 28

I. J. C., B. M. No. 13. See Little Vermilion Lake Sheet:
On a nail in pine stump 25 feet east of a jack pine on Canadian side opposite a 12 inch white pine on American side, just at head of rapids of Little Vermilion Narrows. Approximate elevation, Public Works, Canada, Datum..... 508. 25

I. J. C., B. M. No. 14. See Sand Point Lake Sheet:
On a root of an 8 inch white pine on east bank of east (Steamboat) channel at Crane Narrows, in Township 68 North, Range 17 West of 4th meridian, Section 36, Lot 8. Tree is well blazed and just at the head of the rapids. Approximate elevation, Public Works, Canada, Datum..... 509. 05

I. J. C., B. M. No. 15. See Little Vermilion Lake Sheet:
Edge of coin driven edgewise into a ledge cut in the root of a well blazed 18 inch white pine in a bay on the east bank just at the outlet of Crane Lake, Township 67 North, Range 17 West of 4th Meridian. Section 12, Lot 7. Approximate elevation, Public Works, Canada, Datum..... 509. 20

I. J. C., B. M. No. 16. See Little Vermilion Lake Sheet:
On foot of birch stump in front of office building of logging camp at the south end of Little Vermilion Lake, Township 67 North, Range 16 West of 4th meridian. Section 28. Approximate elevation, Public Works, Canada, Datum..... 509. 71

I. J. C., B. M. No. 17. See Namakan Lake Sheet:
This is a U. S. & C. B. S. bench mark on Namakan Lake, on the east side of a small harbor down to which a road comes from Knox's place at Kettle Falls. The bench mark is on a nail in the base of a well blazed poplar tree about 200 feet north of a point which is one-half mile from the harbor entrance. The tree is about 2 miles east from the outlet of Namakan Lake. A large rock point is just west of the bench mark across the bay. Approximate elevation, Public Works, Canada, Datum..... 505. 6

I. J. C., B. M. No. 18. See Namakan Lake Sheet:
This is a U. S. & C. B. S. bench mark, and is located on a pine tree eighteen inches in diameter, on long rocky point on the south east part of Gold Island. Approximate elevation, Public Works, Canada, Datum... 508.3

I. J. C., B. M. No. 19. See Namakan Lake Sheet:
This is a U. S. & C. B. S. bench mark, on the south east shore of Six Deer Island. The bench mark is on a spike in the base of a 20 inch pine tree which can be seen from the open lake. This tree is also marked T. B. G. No. 36. ISLAND No. 13. Approximate elevation, Public Works, Canada, Datum..... 509.5

I. J. C., B. M. No. 20. See Sand Point Lake Sheet:
This is a U. S. & C. B. S. bench mark, on a nail on the north base of an 8 inch pine tree on the south west corner of the island north of Blind Pig Island, which is Lot 1, Section 28, Township 69 N., Range 17 W., St. Louis Co., Minnesota. A tree blazed and marked ISLAND No. 9, T. B. G. 36, is 100 feet north of the bench mark. Approximate elevation, Public Works, Canada, Datum..... 508.8

I. J. C., B. M. No. 21. See Sand Point Lake Sheet:
This is a U. S. & C. B. S. bench mark, located on a nail in the base of a 6 inch pine tree on a point on the west side of Gull Island. Approximate elevation, Public Works, Canada, Datum..... 508.3

I. J. C., B. M. No. 22. See Sand Point Lake Sheet:
At south end of portage between Namakan and Sand Point Lakes, in Lot 2, Section 34, Township 69 North, Range 17 West of 4th meridian; on a leaning tree 7″ in diameter, 100 feet west of trail and about 100 feet from lake. Approximate elevation, Public Works, Canada, Datum..... 520.49

APPENDIX III

OFFICIAL REFERENCE TO INTERNATIONAL JOINT COMMISSION FROM UNITED STATES GOVERNMENT

DEPARTMENT OF STATE,
Washington, June 27, 1912.

INTERNATIONAL JOINT COMMISSION
OF THE UNITED STATES AND CANADA,
Washington, D. C.

SIRS:

I have the honor to inform you that at the joint request of the Government of the United States and of the Government of the Dominion of Canada, under the provisions of Article IX of the Treaty of January 11, 1909, between the United States and Great Britain, the questions or matters of difference set forth below, which have arisen between them involving the rights, obligations, or interests of each in relation to the other, or to the inhabitants of the other, along their common frontier between the United States and the Dominion of Canada, are hereby referred to the International Joint Commission for examination and report upon the facts and circumstances of the particular questions and matters referred, together with such conclusions and recommendations as may be appropriate.

The questions so referred are as follows:

1. In order to secure the most advantageous use of the waters of the Lake of the Woods and of the waters flowing into and from that Lake on each side of the boundary for domestic and sanitary purposes, for navigation and transportation purposes, and for fishing purposes, and for power and irrigation purposes, and also in order to secure the most advantageous use of the shores and harbours of the Lake and of the waters flowing into and from the Lake, is it practicable and desirable to maintain the surface of the Lake during the different seasons of the year at a certain stated level, and if so at what level?

2. If a certain stated level is recommended in answer to Question 1, and if such level is higher than the normal or natural level of the Lake, to what extent, if at all, would the Lake, when maintained at such level, overflow the low lands upon its southern border, or elsewhere on its border, and what is the value of the lands which would be submerged?

3. In what way or manner, including the construction and operation of dams or other works at the outlets and inlets of the Lake, or in the waters which are directly or indirectly tributary to the Lake or otherwise is it possible and advisable to regulate the volume, use and outflow of the waters of the Lake so as to maintain the level recommended in answer to Question 1, and by what means or arrangement can the proper construction and operation of regulating works, or a system or method of regulation, be best secured and maintained in order to insure the adequate protection and development of all the interests involved on both sides of the boundary, with the least possible damage to all rights and interests, both public and private, which may be affected by maintaining the proposed level?

I have the honor to add that the Government of the United States will be glad to assist the Commission in obtaining any information which it may desire in the course of its investigation of the matters herein referred for its examination and report.

I am, Sirs,

Your obedient servant,

(Sgd) P. C. KNOX.

APPENDIX IV

CORRESPONDENCE TRANSMITTING KENNEDY AFFIDAVIT TO COMMISSIONER OF CROWN LANDS

The following letter, dated Ottawa, 24th October, 1895, shows that the affidavit of Mr. James C. Kennedy was communicated to the Department of Public Works, Ontario, by the late Mr. John Mather, Vice-President of the Keewatin Power Company, Limited:

THE KEEWATIN POWER COMPANY, LIMITED,
Ottawa 24th October, 1895.

SIR: The Keewatin Power Company (Limited) have considered the possibility that at some future time, complaints may be made that the waters of the Lake of the Woods are raised unduly by reason of the company's works, therefore, the company have caused marks to be made on the banks by their engineer, to shew the high-water mark of former years; he has prepared a map, shewing the localities where the marks are made, and made affidavit to the same. I have been instructed by the Board of Directors to send you a map, and affidavit, with a request that if you consider it proper to do so, the same may be fyled by the Ontario Government, so that if need be, it may be used as evidence.

It has been suggested that some Departmental officer might visit the marks, and verify their existence, in conformity with map, and affidavit.

The Keewatin Power Company will be much pleased if you will answer this, so that if you favour the request, the answer may be fyled with the Company's papers.

I have the honour to be, Sir,

Your obedient servant

THE KEEWATIN POWER COMPANY (LTD.),
(Sgd) JOHN MATHER, *Vice President.*

Hon. A. S. HARDY,
Commissioner of Crown Lands, Toronto.

The receipt of this communication was acknowledged as follows:

DEPARTMENT OF CROWN LANDS.
Toronto, November 8th, 1895.

DEAR SIR: I am directed by the Commissioner of C. Lds. to acknowledge receipt of your letter of the 24th ult., enclosing a map of part of the Lake of the Woods, showing the location of certain marks made by the engineer of the Keewatin Power Company at certain points on the Lake of the Woods to show the high water mark of former years, together with an affidavit by Mr. J. C. Kennedy, the said engineer, dated September 13th, 1895, setting out the facts relating to said marks and to say that the map & affidavit together with your letter has been filed with the papers relating to said company in this office. It is too late this season for anyone from this Department to visit and verify said marks.

Yours truly,

(Sgd) AUBREY WHITE,
Asst. Commissioner.

(Sgd) G. B. K.

JOHN MATHER, Esq.,
Vice President, Keewatin Power Company,
Theodore Street, Ottawa.

APPENDIX V

LETTER OF MR. R. P. FAIRBAIRN TO MR. A. V. WHITE RE REGULATION OF THE NORMAN DAM BY THE DEPARTMENT OF PUBLIC WORKS, ONTARIO

When preparing their Report, the Consulting Engineers desired to ascertain what action the Department of Public Works, Ontario, had taken with respect to the request made by the United States Federal Authorities for a minimum stage of 7.2 on the Warroad gauge. Mr. R. P. Fairbairn, Deputy Minister of the Department, was unable to locate a communication upon the subject which he, in 1906, when Provincial Public Works Engineer, had sent to his Minister. Inasmuch as the Consulting Engineers were proceeding to press with the Text of their Report, and desired to publish a statement authoritatively setting forth this part of the early history of matters relating to the Lake of the Woods levels, Mr. Fairbairn, on August 31, 1915, made an official statement as below reproduced. This statement is quoted from on page 12 of the Text of the Report.

It may be pointed out that, subsequently, Mr. Fairbairn's letter, dated June 20, 1906, was located and received his identification. This letter, as identified, was filed at the Winnipeg Hearings on February 3, 1916, as Exhibit P, and is published on pages 435–6 of the printed *Final Public Hearings*, 1916. (The date, June 20, 1916, given for the letter in the *Hearings* is a typographical error, and should be June 20, 1906. Another error exists on page 435, viz, the expression *as low as 6″ 0″ for several days* should read *as low as 6′ 0″ for several days*).

Mr. Fairbairn's letter of August 31, 1915, is as follows:

TORONTO, *August 31st, 1915.*

ARTHUR V. WHITE, Esq., C. E.,
Consulting Engineer,
Confederation Life Building.

DEAR SIR: You have asked me to give a memorandum confirmatory of some of the statements which I have made to you in course of conversation during the last two or three years, relating to inquiries made by you regarding the Norman Dam, situated at the outlet of the Lake of the Woods at Kenora. The matter of special importance in connection with our regulation of the Norman Dam, is the fact that this dam is operated by the Ontario Government, primarily in the interest of navigation.

During what has been referred to as the mining boom in the vicinity of the Lake of the Woods and Shoal Lake, and in the Rainy Lake District, quite a stimulus was given to navigation. Persons operating boats, however, found that they were considerably inconvenienced by the level of the lake falling to low stages.

In 1898 the Public Works Department, Ontario, entered into an agreement with the Keewatin Power Company, by which permission was secured to operate the Norman Dam in the interests of navigation. A man was stationed at the Dam for the purpose of operating the stop-logs. The general operation of the Dam may briefly be stated as follows:

During the early period of navigation, before the time of flood water, the minimum elevation required for navigation is maintained. When flood water is anticipated, the Dam is opened to allow for the gradual escape of the flood water to prevent it rising so high in the Lake of the Woods as to interfere with the carrying on of operations by various interested parties dependent on the level of the Lake. Caution is also exercised to prevent the backing up of the water below the Dam by its too rapid discharge, as to disadvantageously affect the power interests at the outlet.

It is perhaps unnecessary to do more than state that the Department has not made any investigation of the general water-shed, and has had to depend for its guidance in the operation of the Dam upon such information as could be accumulated from gauge readings, and experience gained during former years.

In 1906, there was brought to the attention of this Department, a recommendation made by the United States Chief of Engineers, War Department, that the level of the Lake of the Woods be not permitted to fall below a stage of 7.2 on the Warroad gauge. This 7.2 was taken to be approximately an equivalent of 100.90 on the gauge which the Public Works Department had established in the vicinity of Kenora. In making this request, the Chief of Engineers pointed out that there were several water power companies at or near the dam, which would be benefited by the maintenance of the Lake at the highest possible datum.

After giving this matter consideration, it was decided that the 7.2 asked for as a *minimum* stage, was too high because it would not make provision for the handling of the flood water without causing stages at certain seasons of the year to be much higher than this 7.2. I was Chief Engineer of the Department of Public Works at that time, and reported that a *minimum* stage of 7.2 would not be in the interest of all parties concerned, and that the interest of navigation, both in Canada and the United States, could no doubt be served by keeping the level of the Lake in the near vicinity of from 100 to 101 on the gauge at Kenora. Consequently, in the interests of navigation, as conducted by both the United States and Canada, as nearly as possible what may be called a general stage, instead of a *minimum* stage, of 7.2 has been maintained.

In conclusion, I might say that at times the discharge from the Lake of the Woods water-shed has occurred in a manner for which our experience furnished no guide, but on the whole I believe that the records show that the variation of level on the lakes is well within what could have been anticipated, for navigation purposes, without having much more extensive information of the water-shed than was available.

Yours truly,

R. P. FAIRBAIRN,
Deputy Minister Public Works.

APPENDIX VI

ADDITIONAL DEPARTMENTAL CORRESPONDENCE

File: Warroad 6/1

DEPARTMENT OF STATE,
Washington, February 1, 1908.

The honorable the SECRETARY OF WAR.

SIR: Protests have been filed in this department in behalf of the settlers on the southern shore of the Lake of the Woods on the northern border of Minnesota against the elevation of the surface of that lake above its normal level as existing at the time they located there, which they allege has resulted from the damming of one or more of the outlets on the Canadian side of the lake, and in consequence of which they claim that their lands have been submerged.

It appears that under the plans for the improvement of Warroad Harbor on this lake, in accordance with the plans approved by Congress and carried out under the direction of the War Department, it is essential that the level of the lake be maintained at 7.2 feet on the gauge at Warroad Harbor, and in May, 1905, the Secretary of War wrote to the Secretary of State requesting that an arrangement be entered into with the British Government by which a dam across one of the outlets of the Lake of the Woods, which was under the control of the Provincial Government of Ontario, and by means of which the level of the lake could be to some extent regulated, should be so operated as to prevent the level of the lake from falling below the datum of 7.2 feet on the Warroad Harbor gauge. It does not appear, however, what relation this level bears to the normal level of the lake under natural conditions and in connection with the present protests I desire to obtain this information, and also any further information which the Department may have showing the changes which have taken place in the level of the lake in recent years with reference to that gauge, and the relation between the present level of the lake and the datum of 7.2 feet on that gauge.

I have the honor to be, sir,
Your obedient servant,

ROBERT BACON,
Acting Secretary.

3031/52 [2d indorsement.]

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, Feb. 6, 1908.

Respectfully referred to Maj. F. R. Shunk, Corps of Engineers, for report, giving the information requested by the Department of State as far as may be practicable.

By command of Brig. Gen. Mackenzie:

J. B. CAVANAUGH,
Captain, Corps of Engineers.

File: Warroad 6/1. [3rd indorsement.]

UNITED STATES ENGINEER OFFICE,
St. Paul, Minn., February 15, 1908.

1. Respectfully returned to the Chief of Engineers.

2. Before work was begun at Warroad, a gauge with arbitrarily assumed zero was set in the lake at that place. The mean level of the lake during the open season was assumed to be 7.2 feet, and the depths to be dredged regulated accordingly. This

level was assumed from the best information obtainable; it was not based upon actual measurements. Gaugings have been taken since that time and records are on file for the years 1899, 1903, 1904, 1905, 1906, and 1907. The mean level of the lake during the open seasons of these six years has been 7.15 feet, so that it appears that the assumed level was very nearly correct.

3. The lake is subject to considerable changes of level. High and low waters during the open seasons of the years above referred to were as follows:

	Low water.	High water.		Low water.	High water.
1899	6.30	8.71	1905	4.70	9.00
1903	6.19	8.06	1906	5.60	8.20
1904	5.10	7.10	1907	5.10	8.90

There has been nothing unusual in the variations during the past year, and I am of opinion that they were due to natural causes and not to the operation of dams.

FRANCIS R. SHUNK,
Major, Corps of Engineers.

30371/52.

File: Warroad 6/2.

U. S. ENGINEER OFFICE,
St. Paul, Minn.

Referring to the attached letter of inquiry from the Secretary of State, of Feb. 1, 1908, relating to the elevation of the surface of Lake of the Woods above its normal level, etc., I have the honor to submit herewith copies of the readings of the U. S. Engineer gauge, at Warroad, Minn., as they have been recorded under the direction of this office since 1899, together with a summary of the high and low water levels and mean open water season levels of said lake, etc., and a table of the rainfall record of the nearest observation station during the past 20 years.

The 7.2 foot elevation on the Warroad gauge, the standard elevation for the improvement of Warroad Harbor, when that work was commenced was assumed as mean open water season level of the lake, from all information then obtainable.

With reference to the control of the surface level of the Lake of the Woods, by Canadian dams, at the outlet, my report of September 16, 1905 (Warroad File No. 2, p. 298), and Mr. T. M. Fowble's report of a visit to the dam at Keewatin, Ontario, June 30, 1899, are respectfully referred to.

With reference to the extent that the level of the surface of the Lake of the Woods has been actually affected by the dams at the outlet except as mentioned in the report above referred to, is not known; but in that connection, it is believed that the observed level variations of the lake surface may readily be accounted for under natural conditions.

The mean annual rainfall at the nearest observation station (Lake Winibigoshish Dam) for the past 20 years, has been 26.66 inches, and it may be noted on the table submitted, that the average rainfall for 8 years prior to 1896 was but 23.32 inches, −3.34 inches less than rainfall above noted, while since 1895 has averaged 28.88 inches, −2.22 inches in excess of the mean annual rainfall.

(From previous information, it may be stated, that the period during which the natural surface level of the Lake of the Woods was established in the minds of the early settlers, was prior to the year 1896, during the low rainfall period above mentioned.)

Under the conditions above mentioned, it is considered that the variations in the said lake surface level have resulted from natural conditions and not from the operation of the dams at the outlet, the only exception being the present winter

level of the said lake, which appears to be abnormally high, after 2 years of less than average rainfall, and it is respectfully recommended that an examination be made as to the present conditions at the outlet of the said lake, at Frog Point and Keewatin, Ontario.

Respectfully submitted.

R. DAVENPORT,
Assistant Engineer.

FEB. 13, 1908.

SUMMARY OF WATER ELEVATIONS, LAKE OF THE WOODS, 1899-1907

[Compiled From Warroad Gauge Readings.]

Year	Low water	High water	Mean level	Mean level of year	Year	Low water	Mean water	High level	Mean level of year
Open Water Season:					Open Water Season:				
1899	6.30	8.71	*7.77		1905	4.70	9.00	‡7.36	6.63
1903	6.19	8.06	†7.17		1906	5.60	8.20	‡7.27	7.23
1904	5.10	7.10	‡6.43		1907	5.10	8.90	‡6.89	6.58

* For 5 months, June to October, inc.
† For 5 months, May to September, inc.
‡ For 6 months, May to October, inc.

The elevation of the lake in January, 1908, was 8.10.

[Copy.]

6970—1: Warroad P.

ST. PAUL, MINN., *June 30, 1899.*

Major FREDERIC V. ABBOT,
Corps of Engineers, U. S. A., St. Paul, Minn.

MAJOR: In conformity with your verbal order of May 8, 1899, I have the honor to herewith submit maps and report of survey made at the mouth of Warroad River, Minn.:

The survey was commenced May 17, 1899, and was completed May 30, 1899.

The instruments used were a Gurley transit and level, and measurement of base line was made with a standard steel tape.

On Thursday, May 25, 1899, I established a gauge at the dock near the Custom House at Warroad, setting the 7-foot mark on the gauge even with the surface of the water.

PRESENT STAGE OF WATER

The minimum depth of water on the present boat course over the bar at the mouth of the Warroad River was 7.3 feet at the time of survey. This is deep enough to permit the entrance of the greater number of vessels now in commission on the Lake of the Woods, during calm weather; a heavy sea coming from an easterly direction would prevent the larger boats from entering the channel.

The channel has an average width of about 100 feet and a depth of 13 feet and over, but is very crooked at different places, which renders navigation difficult after dark, as there are no beacon lights set.

The accompanying maps* show the soundings as taken in the channel and on the sand bar.

FORMER STAGE OF WATER

I was unable to obtain any absolutely reliable information as to former stages of water in the Lake of the Woods, but from what inquiries I made, I estimate that at low water the lake will be 3 feet lower than it was on May 25. I am endeavoring at present to obtain more definite information if possible, and hope to receive the same soon. Attached to this report, please note my letter to Mr. R. A. Mather, of Keewatin, Ontario, and his reply to same.

* Not printed.

LAKE BOATS

The following data concerning boats now in commission on the Lake of the Woods were obtained from Mr. G. P. Phillips, the Canadian Government Inspector of Steamboats, at Rat Portage, Province of Ontario:

Name	Length of Keel	Beam	Draft	Registered Tonnage	Business
Keanora	119.7	28	6	268.89	Passenger and freight.
Edna Bridges	75	17.5	5.5	119.62	Do.
Shamrock	71.5	15.5	5	55.29	Do.
Clipper	69.5	12	5	32.43	Do.
Empress	95.4	20	6	73.43	Tug.
Mary Hatch	107.6	20	7	82.40	Do.
D. L. Mather	92	19	8	70.26	Do.
Monarch	101	15.5	6	105.61	Do.

There are about a half dozen other boats in the passenger business of about 55-foot keel and 10-foot beam, with a draft of from 3½ to 4 feet. There are also about 35 other smaller boats in the fish business, etc.

LAKE TRAFFIC

The freight entering Warroad this season will consist mostly of supplies for railway construction. The supplies for 40 miles of railway will probably be shipped by boat to this point. Mr. Geo. A. Graham, the manager of the Rainy River Navigation Company, informs me that they expect to commence shipping railroad supplies to Warroad about July 1, 1899.

DAM OF KEEWATIN POWER COMPANY

This is a masonry dam constructed across the Winnipeg River in Canada, which is the outlet of the Lake of the Woods, at a point about one mile below the Lake.

At the time of my visit, May 25, to the dam, there were strong rapids in the river between the dam and lake. Mr. Alex McQuarrie, the dam tender, whose postoffice address is Norman, Ontario, informed me that the surface of the river at that time immediately above the dam was 6.60 feet lower than the surface of the lake. The river at the dam has been held 6 feet higher than at present, 6 feet of stop logs being recently removed.

Mr. McQuarrie said that the company does not consider it safe to attempt to hold the water at the dam any higher than 6 feet above the present stage at the dam, although the top of the dam is about 11 feet above the present river surface. The power afforded by the dam is not utilized at present.

Respectfully submitted.

(Signed) T. MILTON FOWBLE,
Surveyor.

[Copy.]

ST. PAUL, MINN., *June 20, 1899.*

Mr. R. G. MATHER,
Mgr. Keewatin Lumber Co., Keewatin, Ontario.

DEAR SIR: The U. S. Government is about to make some improvements at the harbor of Warroad River, on the Lake of the Woods. Mr. Alex McQuarrie informs me that you are one of the owners of the dam built by the Keewatin Power Co., near Rat Portage.

If you can inform us as to the stage of water your company intends to maintain on the gauge in the Lake of the Woods, it will be of valuable assistance to us in determining what work will be necessary at Warroad. If you have any record concerning

the stage of water in the lake at different times for the past three of four years, will you please inform us concerning the same?

In case you have no record, will you please state, to the best of your judgment, how many feet above low-water the lake is at present?

Very respectfully yours,

(Signed) T. MILTON FOWBLE,
U. S. Surveyor.

By direction of
Major FREDERIC V. ABBOT,
Corps of Engineers, U. S. Army, St. Paul, Minn.

[Copy.]

453 THEODORE ST., OTTAWA, ONT.,
4th July, 1899.

T. MILTON FOWBLE, Esq.,
U. S. Surveyor, U. S. Engineer Office, St. Paul, Minn.

SIR: The treasurer of the Keewatin Power Co. has sent to me yours of 20th ult. in which you state that you want to be informed regarding the stage of water that the company intends to maintain on the gauge of the Lake of the Woods. I may say that we have not yet made any definite gauge, none of the power being in use. The works are at present controlled by the Government of Ontario, and will continue to be so till power is leased or sold. To the best of my judgment the level at present may be 8 to 9 feet above low water.

Yours respectfully,

JOHN MATHER, *Vice President.*

APPENDIX VII

EQUIPMENT, ETC., OF RAINY RIVER WATER POWER PLANTS AT INTERNATIONAL FALLS AND FORT FRANCES

The plant of the Minnesota & Ontario Power Company and associated companies at International Falls and Fort Frances is shown in plan on Plate 84 of the Report of the Consulting Engineers (Plates). The plant consists of a power house and paper mill on each side of Rainy River connected by a V-shaped dam pointing upstream. Wasteway capacity for the discharge of the flood waters from Rainy Lake is provided by ten sluices in the Canadian wing of the dam and by six sluices at the head of the old Canadian Canal. Each sluice has a width of 10 feet, a sill elevation of 477.5 Public Works, Canada, datum and an arch crown elevation of 490.0. The discharge through these sluices is controlled by two-piece wooden sluice gates, which are raised by means of a motor-driven hoist. In addition to these wasteways there is a 12-foot log sluice with a sill elevation of 487.0.

The dam is of masonry construction, rubble-faced and capped with concrete. The spillway section of the dam is about 450 feet long, with crest at elevation 497, and is provided with flashboard supports and decked to allow passage from one side to the other.

In the American power house, the power developed is used only for the purpose of grinding wood pulp. The installation consists of six units of four 39-inch wheels, each unit direct connected to a battery of four wood-pulp grinders. The wheels are of the "Smith" type, built by the S. Morgan Smith Co., of York, Pennsylvania. At a head of 28 feet, for which the turbines were selected, the manufacturers' rating for each unit of four wheels is 2011 horsepower, 226 r. p. m. and 782 c. f. s. discharge. The center of shaft is at elevation 483.0 and the elevation of the bottom of the draft tubes is 461.0. The values of power and discharge given here are five per cent less than those listed on the manufacturer's catalogue, on account of the larger shaft required when four wheels are attached to a single shaft. In operation these wheels generally run at full gate with constant efficiency at all heads, the speed varying with the different heads as given by the manufacturers' catalogue, and the power and discharge being decreased 5% from the rated values for single turbines. The pressure pumps of each grinder act as governors, since the increasing of the turbine speed increases the pump speed and the pressure against the grinder, with the result of more power being used in grinding the wood. It has been stated that the speed of grinders should not exceed 260 r. p. m. on account of the possibility of the bursting of the grindstones.

On the Canadian side, power is used both for the purpose of grinding wood pulp and for generating electric power. The pulp grinding installation here consists of five units of four 36″ wheels, each unit direct connected to a battery of three grinders. The wheels are of the "Smith" type built by the S. Morgan Smith Company of York, Pennsylvania. At a head of 28 feet, the manufacturers' rating for each unit of four wheels is 1716 horsepower, 244 r. p. m. and 667 c. f. s. discharge. The center of shaft is at elevation 483.0 and the bottom of draft tube at elevation 460.0. The same conditions of operation as described for the grinders in the American plant are applicable to this installation. The first of the Canadian grinders were operated in June 1914, the entire present installation being in use by August, 1914.

The hydro-electric portion of the Canadian power house generates electric power principally for the driving of the paper-making machinery and the lighting of the plant, a small block of power being used in lighting the two adjacent towns. This installation consists of four units of four 36″ wheels, each unit direct connected to a 1250 K. V. A. 3-phase, 60-cycle, 6600 volt generator, regulated by improved Lombard governors. The wheels are of the Holyoke type "C" manufactured by the Holyoke Machine Company of Holyoke, Massachusetts. The manufacturer's rating for each unit of four wheels at a 28 foot head is 1700 horse power and 212 r. p. m. The center of shaft is at elevation 484.0 and the bottom of draft tube at elevation 460.0. The hydro-electric portion of the Canadian power house together with the American grinders has been operated since September, 1910. For a record of power output, head, discharge, etc., for the years from 1910 to 1915, inclusive, see Table 90, volume of Tables, of this Report.

APPENDIX VIII

EQUIPMENT, ETC., OF WINNIPEG RIVER WATER POWER PLANTS

THE WINNIPEG ELECTRIC RAILWAY COMPANY'S PLANT

The hydro-electric plant of the Winnipeg Electric Railway Company is located on the Pinawa Channel of the Winnipeg River. A very complete account of both the historical and physical features of this plant has been presented in a report by Mr. J. T. Johnston of the Dominion Water Power Branch.* This plant was completed in 1906 and during that year furnished the first hydro-electric power used in Winnipeg. The electric power from this plant is used for the purposes of street railway operation, light, heat, and power.

The installation at the Winnipeg Electric Railway Plant consists of nine main units, each unit consisting of four horizontal inward flow runners mounted in pairs and placed longitudinally in the penstocks. Four of the nine units, each have a manufacturer's rating, at a 39-foot head, of 2595 horse power and 200 r. p. m., each unit being direct connected to a 1000 k. w. revolving field, 60-cycle, 3-phase, 2300 volt generator. The remaining five units each have a manufacturer's rating at a 39-foot head of 4788 horse power and 180 r. p. m., each unit being direct connected to a 2000 k. w. revolving field, 60-cycle, 3-phase, 2300-volt generator. The turbines are equipped with Lombard governors. The generators are guaranteed to operate at full load at 95.5 per cent efficiency. Excitation is provided by two 100 k. w., 125-volt direct-current machines coupled to two 200-horsepower McCormick turbines, and operating at 600 r. p. m.; and by two 175-k. w., 125-volt exciters coupled to three-phase, 2300-volt induction motors, operating at 514 r. p. m.

The head available for power purposes at this site varies with the season and the flow, the average head being 39 feet. During the winter, ice conditions have at times caused considerable trouble, resulting in a decrease in available head. A flow of about 8000 c. f. s. is required to operate this plant under normal head at the full capacity of the present installation.

The power is transmitted to Winnipeg at 60,000 volts, over a 65 mile duplicate transmission line. In Winnipeg this company has an auxiliary plant and storage battery capable of producing 22,000 horsepower, bringing the total power available for distribution in the city up to approximately 45,000 horsepower. During the winter season of peak load, all of the steam and storage battery plant, in addition to the hydro-electric plant, are operated to capacity.

THE WINNIPEG MUNICIPAL PLANT

The hydro-electric plant † of the City of Winnipeg is located at the Point du Bois Falls of the Winnipeg River, 75 miles in a direct line from Winnipeg. The plans for this plant were begun in the latter part of 1906, but on account of the delay caused by the financial stringency of 1907 the plant was not completed and the initial installation operated until October, 1911.

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* Water Resources Paper No. 3, Department of the Interior, Dominion Water Power Branch, pages 138-148. Also see Watershed Map accompanying this Report.

† See Water Resources Paper No. 3, Department of the Interior, Dominion Water Power Branch pages 148-161. Also see Watershed Map accompanying this Report.

The original installation, completed in April, 1913, consisted of five main units, each composed of a horizontal, double-runner turbine of 5200 horsepower which, at a 45 foot head, has a discharge of 1250 c. f. s., a speed of 164 r. p. m., and a guaranteed efficiency of 84% at full load. Each turbine unit is direct connected to a 3000 k. w., revolving field, 60-cycle, 3-phase, 6600-volt generator. The turbines were supplied by the Messrs. Jens, Orten-Boving & Company, London, and the generators by Messrs. Vickers, Ltd., of River Don works, Sheffield. This original installation is completed by two exciter units, each of 250 k. w. capacity, driven by water turbines running at 500 r. p. m.

In 1914, three additional main units of different design from the original were installed. These units are also of the double-runner, horizontal shaft type, but of larger capacity than the initial units. Official tests gave an output of 7220 brake horsepower at 80 per cent gate opening and 46 foot head or about 7000 horsepower for a 45 foot head. The new units are each direct-connected to a 5000 K. V. A. revolving field, 60-cycle, 3-phase, 6600-volt Westinghouse generator. The installation in 1916 consists of five units of 5200 horsepower each and three units of 7000 horsepower each, or a total of 47,000 turbine horsepower. The normal head at the plant is 45 feet. No ice troubles have been experienced thus far during the period of operation.

Assuming that the eight bays in the uncompleted portion of the power house are equipped with units of similar size to those last installed, the station will have a total capacity of 103,000 turbine horsepower. The power is transmitted to Winnipeg at 66,000 volts over a 77 mile transmission line.

WINNIPEG RIVER POWER COMPANY

The Winnipeg River Power Company, which is controlled by the same interests as the Winnipeg Electric Railway Company, has under way at the present time (1916) the development of the Du Bonnet* site of the Winnipeg River. This site is at a distance of about 80 miles from Winnipeg.

As stated in Water Resources Paper No. 3:

"The station as now designed provides for the ultimate utilization of the entire regulated river flow and will install eight 21,000 horsepower turbines, each running at a speed of 163.3 revolutions per minute, and requiring 4100 cubic feet of water per second, when operating under a head of 56 feet. These turbines will be of the four-runner horizontal shaft type, and will be placed in pits formed in the concrete substructure."

In October, 1914, a railway 13 miles in length was completed by these interests from the Canadian Pacific line at Lac du Bonnet down to the power site. At the time of the Final Public Hearings before the Commission at Winnipeg in February, 1916, the plans had been prepared for the beginning of construction whenever conditions for financing the enterprise should become sufficiently favorable.

* See Water Resources Paper No. 3, Department of the Interior, Dominion Water Power Branch, Appendix II, page 333.

APPENDIX IX

LIST OF LAKE OF THE WOODS REPORTS, HEARINGS, ETC.

In order to assist any person reading the various records of the Commission dealing with the Lake of the Woods Reference in identifying certain volumes referred to, the following annotated list of Reports, Hearings, etc., has been prepared. It specifically describes the various publications issued by the Commission prior to the publication of its own Report.

REPORT OF CONSULTING ENGINEERS

1. TEXT—Advance Sheets of uncorrected proof of Text, 1915.

   Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels—Advance Sheets of Text—1915.

   NOTE.—In 1915, in order to enable the Commission to deal with some special matters, the Consulting Engineers had bound, in page form with paper covers, about a dozen copies of uncorrected proof of portions of the Text of their forthcoming Report, accompanied by over forty pages of illustrations. This volume was soon superseded by the Advance Sheets (cloth bound) copy of Text issued later in 1915. Reference is here made to the Advance Sheets of uncorrected proof, because they were referred to in the course of some of the meetings held by the Commission.

2. TEXT—Advance Sheets, 1915.

   Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels. Text. By Adolph F. Meyer–Arthur V. White, Consulting Engineers. 8vo., 272 pp., with small maps and numerous illustrations. Washington, D. C., 1915.

   NOTE.—At the Hearings this volume was sometimes referred to as the "green covered book."

3. PLATES—Advance Sheets, 1915.

   Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels. Plates (not including half-tones). By Adolph F. Meyer–Arthur V. White, Consulting Engineers. 8vo. Plates 1–143 and Plan of Manitou Rapids, Rainy River. Washington, D. C., 1915.

   NOTE.—At the Hearings this volume was sometimes referred to as the "brown covered book."

4. TABLES—Advance Sheets, 1915.

   Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels. Tables. By Arthur V. White–Adolph F. Meyer, Consulting Engineers. 8vo., 291 pp. Washington, D. C., 1915.

   NOTE No. 1.—At the Hearings this volume was sometimes referred to as the "blue-covered book."

   NOTE No. 2.—These "Advance Sheets," consisting of about 100 bound copies each of the three volumes of Text, Plates and Tables, were issued by the Commission in 1915 in order to afford certain Government departments and other parties especially interested in the Lake of the Woods investigation, the earliest opportunity to familiarize themselves, in advance of contemplated further public hearings, with the available engineering data and considerations presented by the consulting engineers.

5. TEXT—Final Report, 1916.

   Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels. Text. By Arthur V. White–Adolph F. Meyer, Consulting Engineers. 1916. 8vo., 314 pp., including supplement and appendices, small maps and numerous illustrations. Washington, D. C., 1917.

   NOTE.—This edition is substantially the same as the "Advance Sheets" (see item 2 above) with the addition of a Supplement—which deals chiefly with the flood situation of 1916—and some appendices.

6. PLATES—Final Report, 1916.

Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels. Plates (not including half-tones). By Adolph F. Meyer–Arthur V. White, Consulting Engineers. 8vo. Plates 1–144. Washington, D. C., 1916.

NOTE.—The Plates 1-143 and the Manitou Rapids Plan (now No. 144) are as in item 3 above. There have been added Plates 11A, 67A, 99A, 104A, 124A, 135A, 135B, 135C, and 139A.

7. TABLES—Final Report, 1916.

Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels. Tables. By Adolph F. Meyer–Arthur V. White, Consulting Engineers. 8vo., 330 pp. Washington, D. C., 1916.

NOTE.—In this item, pages 1 to 290 contain the data published in item 4, and also at a few places certain data for 1915, which have been inserted. Pages 291-330 contain the bulk of the supplementary data available at the date of publication.

8. WATERSHED MAP.

Watershed of the Lake of the Woods. Compiled mainly from maps of the Department of the Interior, Canada, and Map of the State of Minnesota, prepared (1912) by U. S. Geological Survey. To accompany Report of Engineers relating to the investigation of the levels of the Lake of the Woods and tributary waters.

Scale 1 : 500,000=7.89 miles to 1 inch. Adolph F. Meyer–Arthur V. White, Consulting Engineers.

NOTE.—Folded and bound to accompany Final Report of Consulting Engineers.

9. ATLAS.

Atlas to accompany Report to International Joint Commission Relating to Official Reference re Lake of the Woods Levels. By Arthur V. White–Adolph F. Meyer, Consulting Engineers. Ottawa, 1915.

NOTE.—The Atlas was not issued for general distribution. However, copies were deposited, in each country, with various departments of the Federal, State and Provincial Governments; also in certain Government, university, and public libraries in localities likely to be most interested in the Lake of the Woods region. A complete list of its contents will be found in Text of Report of Consulting Engineers, p. 45. (Item 5 above.)

PUBLIC HEARINGS

10. PUBLIC HEARINGS AND PROGRESS REPORT.

Progress Report of the International Joint Commission on the Reference by the United States and Canada in re Levels of the Lake of the Woods and its tributary waters and their future regulation and control, including *Public Hearings* at International Falls and Warroad, Minnesota, and Kenora, Ontario. Dated January 16, 1914. 8vo., 186 pp. Washington, D. C., 1914. Containing:

Letter of Reference, pp. 3–4.

Progress Report, pp. 5–15.

Appendix—Public Hearings:

Hearings at International Falls, Minn., September 17, 1912, pp. 19–82.

Hearings at Warroad, Minn., September 18, 1912, pp. 82–129.

Hearings at Kenora, Ont., September 20, 1912, pp. 129–186.

NOTE.—These Hearings contain testimony presented at International Falls, Minnesota, by Government officials and private parties representing the interests of navigation, riparian owners, and power development on Rainy River and Rainy Lake. At Warroad, Minnesota, further testimony was submitted relating to agriculture around the shores of the Lake of the Woods, to fishing, and to the interests of the town of Warroad. At Kenora, Ontario, further testimony was presented respecting navigation, power development at the outlets of the Lake of the Woods and on the Winnipeg River, including industries dependent upon the use of this power, and to the controlling structures at the outlets of the Lake.

11. FURTHER PUBLIC HEARINGS.

Hearings of the International Joint Commission on the Reference by the United States and Canada in re Levels of the Lake of the Woods and its tributary waters and their future regulation and control, being *Further Public Hearings* at International Falls and Warroad, Minn., and Kenora, Ontario, September 7–14, 1915. 8vo., 511 pp. Washington, D. C., 1915. Containing:

Letter of Reference, pp. 3–4.

Hearings at Warroad, Minn., September 7–9, 1915, pp. 5–283.

Hearings at International Falls, Minn., September 10, 1915, pp. 283–348.

Hearings at Kenora, Ontario, September 13–14, 1915, pp. 348–505.

Index, pp. 507–511.

NOTE.—At Warroad, Minnesota, statements were made by the Consulting Engineers and testimony submitted by Government officials and private parties respecting navigation, agriculture along the shore of the Lake, fishing, and the drainage ditch systems of Minnesota. Considerable testimony was also submitted relating to the value of agricultural lands. At International Falls, Minnesota, statements were made by the Consulting Engineers, and further testimony was presented by Government officials and private parties, relating to the effect of the levels of Rainy Lake and Rainy River upon the towns of Fort Frances and International Falls; upon the Canadian Northern Railway and other interests; also respecting the effect of various lake levels upon riparian owners. At Kenora, Ontario, statements were made by the Consulting Engineers, and testimony submitted by Government officials and other parties respecting the navigation, fishing, lumbering, mining, summer campers, and other interests.

12. FINAL PUBLIC HEARINGS.

Hearings on the Reference by the United States and Canada in re Levels of the Lake of the Woods and its tributary waters and their future regulation and control; being *Final Public Hearings* at International Falls, Minn., January 28–29, 1916, and Winnipeg, Manitoba, February 1–4, 1916. 8vo., 539 pp. Washington, D. C., 1916. Containing:

Letter of Reference, p. 3.

Hearings at International Falls, Minn., January 28–29, 1916, pp. 5–197.

Hearings at Winnipeg, Man., February 1–4, 1916, pp. 197–466.

Appendix A—House Document No. 92, Fifty-sixth Congress, second session, being examination, in 1900, of Warroad Harbor and Warroad River, Minn., and correspondence relating thereto; also various Government correspondence up to 1911 respecting Warroad Harbor, etc.; also various memoranda and statements relating to the Birch Lake Diversion Project, pp. 467–508.

Appendix B—Statement of Shevlin-Clarke Co., Ltd. (in re levels of the Lake of the Woods), pp. 509–514.

Appendix C—Diplomatic correspondence, Lake of the Woods Levels. From the British Embassy at Washington, D. C., and from various Government officials in the United States and Canada, pp. 515–526.

Appendix D—Certificates of the Auditor of the State of Minnesota in re Lands Patented to the State, pp. 527–531.

Errata: Mr. Wyvell requests that pages 342 and 343 be amended, p. 533.

Index, pp. 535–539.

NOTE.—At International Falls, Minnesota, testimony was submitted respecting the values of agricultural lands, and also respecting how interests would be affected at Fort Frances and at International Falls, at the Indian Reserves and at the saw mills. Testimony was also submitted respecting the effect of various lake levels upon riparian owners on the Lakes immediately above Kettle Falls. At Winnipeg, Manitoba, statements were made by the Consulting Engineers. Government officials and private parties submitted testimony relating to camping and summer tourist interests; to industrial and power interests at the outlets of the Lake and on the Winnipeg River; to the Canadian Northern Railway; to the State of Minnesota re the judicial ditches and drainage systems of the State; to the Hydro-Electric Power Commission of Ontario; and to other interests.

13. FINAL ARGUMENTS.

Arguments on the Reference by the United States and Canada in re Levels of the Lake of the Woods and its tributary waters and their future regulation and control, being *Final Arguments* at Washington, D. C., April 4–8, 1916. 8vo., 295 pp. Washington, D. C., 1916.

Index, pp. 293–295.

NOTE.—Final Arguments were submitted and statements made by various counsel representing power interests at International Falls, Minnesota, and Fort Frances, Ontario, at the outlets of the Lake of the Woods, and upon the Winnipeg River; the agricultural interests on the south shore of the Lake; fishing interests; the Government lands of the State of Minnesota; the interests of the town of Fort Frances; the interests on Rainy Lake, and the interests of the Province of Ontario; the State of Minnesota; the Government of the United States, and of the Government of the Dominion of Canada.

14. APPENDIX TO HEARINGS.

Appendix to Hearings on the Reference by the United States and Canada in re Levels of the Lake of the Woods, and its tributary waters and their future regulation and control, being certain exhibits and other papers filed with the Commission. 8vo., 98 pp. Washington, D. C., 1916. Containing:

Exhibit R: List of Steam Vessels on the Lake of the Woods, p. 3.

Exhibit T: Table of Kennedy's Chiseled High-water Marks, pp. 3–4.

Minnesota Exhibit A: Appraisals of State Flowage Lands, St. Louis County, pp. 5–19.

Minnesota Exhibit B: Appraisals of State Flowage Lands, Koochiching County, pp. 21–38.

Minnesota Exhibit C: Memorandum of Sales of State Lands, Townships 69, 70, and 71 north, ranges 23 and 24 west, Koochiching County, pp. 39–43.

Minnesota Exhibit F: Lands belonging to State of Minnesota, Rainy Lake and Rat Root River districts, pp. 44–45.

Minnesota Exhibit G: Lands belonging to State of Minnesota, Kettle Falls district, pp. 46–47.

Settlers' Exhibit A: Rainy Lake and Rat Root River districts, pp. 48–49.

Exhibit 11: Statement by the Winnipeg Electric Railway Co., Chronological History, pp. 50–61.

Ontario & Minnesota Power Co., Exhibit A: Contracts between the Commissioner of Crown Lands and Edward W. Backus, pp. 61–74.

Exhibit 18: Memorandum by office of the Chief of Engineers, U. S. War Department, dated Feb. 25, 1908, re Levels of Lake of the Woods, pp. 75–80.

Memorandum of Chief Reclamation Engineer of Canada (filed with Commission), pp. 80–91.

Exhibit No. 14: Certificate as to Assessed Value of Land, pp. 91–93.

Exhibit 7, by Mr. Laird: Memorandum of Deeds from Registry Office for Beltrami County, p. 93. Memorandum of Searches in Registry Office for Beltrami County, p. 94. Memorandum of Deeds from Registry Office at Roseau, pp. 94–96.

Index: pp. 97–98.

15. REPORT ON THE FLOOD OF 1916.

Flood Conditions on Boundary of Minnesota and Ontario. Report on The Flood Conditions in the Lake of the Woods and Rainy Lake Districts, Minnesota and Ontario; together with a general statement of the water levels, interests involved and methods of relief, by Charles A. Magrath and James A. Tawney, members of the International Joint Commission, presented by Mr. Nelson, June 20, 1916. Senate Document No. 647, 64th Congress, 1st session. Washington, D. C., 1916. 10 pp.

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